Expanding agroforestry in Minnesota, USA: assessing the potential for silvopasture as an alternative to passive woodland grazing

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Abstract

177,791 ha of woodlands in Minnesota, USA are grazed. Often these woodlands are not managed specifically for timber or cattle benefits. This lack of management often leads to decreased timber value and reduced forage yields. Silvopasture is a potential alternative to this lack of land management on Minnesota woodlots. Silvopasture is a type of agroforestry that intentionally combines trees, forage and livestock in an intensively-managed system. However, very limited information exists about silvopasture use in Minnesota. This three-year study (2013-2015) examines the potential for silvopasture success in Minnesota through comparing production of unmanaged woodland grazing, silvopasture and open pasture sites. The study collaborated with three farmers in Central Minnesota to assess these three grazing systems on their land. Silvopasture paddocks were established through thinning and seeding woodland areas. The study assessed forage production, forage quality, species diversity, and livestock performance. Forage production was generally greater in silvopasture systems compared to unmanaged woodland grazing systems, and forage quality was lower in open pasture systems, at least during the first year. Additionally, species diversity was typically lowest in open pasture systems, and comparable between silvopasture and woodland areas. Livestock performance was similar between the grazing systems. Results indicate that silvopasture has potential in Minnesota, but more research is needed to develop specific

management guidelines as well as monitor silvopasture for longer periods of time.

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Introduction

With the environmental impacts of agriculture and food production on the forefront of the environmental movement, it has become increasingly important to explore new opportunities to enhance environmental as well as economic benefits of agricultural systems. Approximately 40% of farms in Crow Wing County, Minnesota, are cattle producing (NASS 2015). Landowners looking to diversity income and land use practices can consider silvopasture. Silvopasture is the intentional combination of trees, forage and livestock in an intensively managed system. Many landowners already practice some kind of woodland grazing. Thus, switching to silvopasture has the potential to be an easy way to improve efficiency, productivity, and environmental benefits from grazing operations.

Unmanaged woodland grazing has been shown to be detrimental to trees and livestock production. Silvopasture studies around the world show a variety of benefits and challenges within these systems. Common benefits around the world include timber sales, enhanced microclimate, fewer weeds, reduced forest fire, reduced animal stress, minimized soil erosion and diversified income. Some challenges include the complex management required (and continued thinning), competition between forage and trees, trees falling onto fences, lack of timber market, and the time required to establish the system and break even (Cubbage et al. 2012).

While silvopastoral systems can have a wide range of benefits for landowners and the environment, they are complex systems that require careful management. Silvopasture has been more intensively researched in the southern region of the United States with pine plantations, but little research has been done with hardwood systems especially in the upper Midwest. This study was designed to assess the potential for success of silvopasture systems and begin to develop management guidelines of the practice, since silvopasture is regionally sensitive and management techniques will vary by region.

The overall hypothesis for this study is that silvopasture systems will outperform unmanaged woodland systems due to improved management and microclimatic conditions. The following objectives were used to test this hypothesis:

1. To determine what the current management techniques are for open pastures and silvopastures, especially in the temperate Midwest;
2. To determine the current practices and knowledge base of natural resource professionals and landowners in central Minnesota on silvopasture;
3. To determine barriers to adoption of silvopasture in central Minnesota;
4. To assess differences in forage productivity, forage quality, livestock performance between open pasture, silvopasture and woodland grazing systems;

5. To assess differences in environmental benefits such as herbaceous diversity, soil health and infiltration rates between open pasture, silvopasture and woodland grazing systems; and
6. To determine management implications from the collected data.

Chapter 1. Background and management of silvopasture systems

1.1. The history of woodland grazing

Forests are often grazed to take advantage of herbaceous understory growth that would otherwise remain unused. Forest gaps, created by natural or human disturbance, often produce grazeable understory vegetation until trees close the canopy (Sharrow 1998). This type of grazing is referred to as passive woodland grazing and is practiced to a varying degree across the country based on individual landowner interests. In Minnesota there are 6.8 million ha of forestland; of that 0.81 million ha are on farms and 37% of those are grazed (Garrett et al. 2004). However, passive woodland grazing rarely results in any benefits to the cattle or the trees. Forage regrowth has been shown to be extremely low in woodland grazing systems especially those with hardwood tree species (Johnson 1952). Johnson (1952) found that by the end of the first grazing season the herbaceous forage and much of the hardwood understory had been used. DenUyl (1945) argued that farm woodlands should not be grazed, stating that cattle will ultimately destroy farm woodlands, due to young tree damage, lack of natural regeneration and changes in canopy structure. Thus, he suggests that complete exclusion of livestock is the only appropriate management technique for woodland production. This view that trees and livestock do no mix is still a common view in forestry today (Garrett et al. 2004). However, with the use of intensive management techniques, such as those used in agroforestry, trees, forage and livestock interactions can be manipulated to enhance woodland grazing (Garrett et al. 2004).

1.1. Silvopasture as a solution

Agroforestry is defined by the Association for Temperate Agroforestry (AFTA 2016) as an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock. Types of agroforestry include alley cropping, forest farming, windbreaks, riparian buffers and silvopasture. Silvopasture is defined as the integration of trees and livestock in an intensively managed system (Nair 1993). While silvopasture has a long history around the world and in North America, research further developing the system started in the 1940s with research into grasses and legumes under shade (Burton 1973). Since then there have been many studies that have further researched the effects of silvopasture management including research into the best management practices themselves. However, there is still relatively little information regarding hardwood silvopasture management especially in the upper Midwest.

1.2. Silvopasture Management

Silvopasture has the potential to improve the utilization of farm woodlands, but it must be managed properly to be successful. Specific management considerations pertaining to initial establishment of the silvopastoral system include selecting forages that will thrive in 40-50% shade, thinning or planting trees to create a desired canopy cover, pruning trees to encourage healthy profitable trees, protecting small trees/seedlings from cattle damage, and moving cows frequently enough to prevent erosion and compaction (Hamilton 2008; Undersander et al. 2014; Center for Agroforestry 2015; Walter 2015).

1.2.1. Forages

It is important to choose shade tolerant cool-season grasses such as Orchardgrass (*Dactylis glomerata*), Smooth Brome (*Bromus inermis*), Kentucky Bluegrass (*Poa pratensis*) and Tall Fescue (*Festuca arundinacea*), for seeding into silvopasture systems to enhance forage productivity (Hamilton 2008; Walter 2015) **Figure 1.2** summarizes shade tolerance of other common forage species. Planting a mixture of different forages help to reduce risks and improve resiliency. Forages should be managed based on specific needs such as cold hardiness, compatibility with other forages, drought tolerance, flooding tolerance and regrowth potential (Hamilton 2008). The seasonal growth patterns of different forages should be taken into account to optimize growth throughout the growing season. Considering a combination of cool-season grasses (that are most productive in the spring and fall), legumes (that start later in the season, but have uniform growth throughout the season) and warm-season grasses (that have the most growth in midsummer when many other species slow due to increased temperatures) will also help improve forage quality (Hamilton 2008).

1.2.2. Livestock

Grazing can stimulate pasture growth, but few forages are adapted to continuous grazing. Most plants require a rest or fallow period and therefore do well in a rotational grazing system (Undersander et al. 2014). The key to a good grazing program is maximizing both forage yield and quality. The best time to graze is immediately following the most rapid growth but before flowering and seeding (Undersander et al. 2014) (**Figure 1.1**). Quality significantly decreases following flowering and heading, because most of the energy is concentrated in producing flowers and seeds, and as plants get taller and stemmier more nutrients get tied up in indigestible forms, such as lignin (Undersander et al. 2014). Yield however is highest when the plant is largest as leaves are larger and more photosynthesis can occur. Plants convert energy from photosynthesis to carbohydrates; these carbohydrates are either used right away for growth (in spring and after grazing) or stored in the roots for future use (in the fall and once plants are large enough that they don’t need the energy for immediate growth) (Undersander et al. 2014). Grazing too frequently doesn’t allow for the replenishment of root reserves resulting in weaker plants, slower recovery and ultimately lower yields. Grazing helps promote growth (through tillering) and keeps the plants vegetative throughout the growing season rather than seeding early (Undersander et al. 2014).

Rotational grazing is the management of grazing where pastures are broken into paddocks. These paddocks are grazed in rotations, allowing for a fallow or rest period where the forage can grow back. Rotational grazing is especially important for silvopasture systems as they are susceptible to overgrazing and soil compaction (Hamilton 2008). The timing of moving cattle should be based on forage growth (and height) not on a rigid time schedule to be successful (Hamilton 2008; Undersander et al. 2014). Some of the benefits of rotational grazing compared to continuous grazing include: improved growth stability during poor growing conditions, greater yield potential, high quality forage availability, decreased weed and erosion problems, and more uniform soil fertility (Undersander et al. 2014). Rotational grazing can be implemented under a variety of intensities depending on management goals, and land/grazing animals being used (**Table 1.1**). Additional benefits of rotational grazing include: economic benefits (specifically compared to confinement farming), time savings (moving from paddock to paddock can be easy if fencing is well planned), environmental benefits (decreased erosion, require minimal pesticides and fertilizers and decreased animal excrement runoff), wildlife benefits (grassland birds), and aesthetics and human health benefits (Undersander et al. 2014). The use of a rotational grazing system can help to reduce compaction and erosion, which can negatively impact tree roots (Hamilton 2008; Center for Agroforestry 2015).

1.2.3. Trees

Silvopasture establishment involves either planting trees in open pasture or altering woodlands to fit silvopasture systems. While planting trees in wide rows is common with pine silvopastures, hardwood trees grow slower and managing existing woodlands for silvopasture use is more feasible. Woodlands should be thinned to create the desired 30-50% shade. Two common silviculture methods that can result in this desired shade amount are shelterwood and group selection. The group selection method creates patches of trees and open gaps while the shelterwood method aims to create a more even dispersal of gaps. In younger stands release thinnings can also be used to create the desired light levels (Garrett et al. 2004).

Managing trees can involve protecting regeneration (either natural or artificial) and pruning. Pruning can be used to improve log values by reducing the size of knots produced by side branches, as open grown trees tend to produce more side branches (Hamilton 2008). Choosing stands with tree species that are less likely to develop epicormic branches such as red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*) and hickory (*Carya* spp.) can also improve log quality (Garrett et al. 2004). Protecting young trees from livestock (browse and hoof damage) is often necessary and can be achieved through group of individual fencing. Natural regeneration is more difficult in silvopasture systems due to livestock presence and planting large seedlings can be more successful. Planting seedlings in rows allows for group fencing to ensure establishment and growth (Garrett et al. 2004; Hamilton 2008).

1.3. Benefits and Limitations

Silvopasture systems take advantage of the beneficial interactions that occur between the different components as well as the microclimate that is present due to these interactions. However, this combination of components can also pose challenges.

1.3.1. Trees and forage

Intermediate shade has been shown to have a variety of effects on forage species depending on climate, site productivity and management practices. However, the presence of trees has been shown to increase forage production and quality (Buergler 2004). Because C3 plants require only 50% of full sun, some C3 cool season grasses actually perform better under shade environments than they do in the sun due to improved efficiency in cooler temperature created by shade. Crude protein has also been shown to be higher in some species in shady environments, while forage digestibility does seem to be lower in shaded environments (Holechek et al. 1981; Lin et al. 2001). Lin et al. (2001) showed that if appropriate species are selected then forage yield, fiber content, crude protein and N balance can be maintained under shade environments. Buergler et al. (2005) showed that forage yields with black walnut and honey locust silvopasture systems peaked at medium tree densities and that light levels under low tree densities were not dissimilar to open pastures.

While some competition between trees and forage is expected, many studies have found that trees do not have a negative effect on soil moisture (Buergler 2004) and soil health is often improved by the presence of trees due to improved soil structure and increased organic matter (Nair 1993).

1.3.2. Trees and livestock

Silvopasture can have positive benefits on cattle performance. Since cattle performance has been shown to decrease with high temperatures (29.4° C) (Cartwright 1955), access to shade and therefore reduced stress can improve cattle performance. The even dispersal of shade in a silvopasture system can also allow for more uniform grazing and resulting improved nutrient distribution from dung compared to open pasture with a few trees (Garrett et al. 2004; Walter 2015). Properly managed pasture and grazing systems can result in decreased competition for trees with shrubs and herbs as well as improved site conditions for tree regeneration due to exposed mineral soil (Lindgren and Sullivan 2012).

Negatively, cattle can damage tree regeneration through browse and hoof damage, resulting in the need for seedling protection. If areas are overstocked cattle can also invoke damage to trees in terms or root and bark damage, as well as soil compaction (Johnson 1952; Garrett et al. 2004). Other limitations can include the added difficulty of maintaining fences in a wooded environment as fallen trees can damage fences requiring more frequent repair than treeless pastures (Center for Agroforestry 2015).

1.3.3. Soil Health

Canopy coverage and the resulting microclimate has been shown to increase soil nutrients by increasing litter quality and decomposition rates, resulting in higher amounts of organic matter (Tripathi et al. 2013). The increased forage production that can be seen in silvopastoral systems specifically compared to woodland sites can lead to increase soil organic matter (Sharrow 1998). While soil compaction and thus infiltration rates are often negatively effected by the presence of cattle, the presence of trees can increase infiltration rates as roots penetrate compact soils (Bartens et al. 2008).

1.3.4. Water quality

Agricultural lands (including cattle ranching) can be a threat to water quality because of nutrient loading. Because of the ability of trees to remove excess nutrients from soil (Nair et al. 2007) as well as the ability of perennial and annual grasses to filter water and increase infiltration rate thus reducing erosion and runoff, silvopasture is a potential solution to many water quality issues. The ability of silvopasture systems to increase ground cover in comparison to woodland grazing systems also leads to decreased runoff and erosion (Johnson 1952). Sovell et al. (2000) showed that rotational grazing can result in reduced fecal coliform levels and turbidity when compared to continuous grazing, and that wood buffers, with almost complete canopy and little vegetative ground cover, can be less effective than vegetative buffers. The benefit of wood buffers is that they provide greater shade cover especially for larger streams/rivers thus reducing water temperature. Silvopasture however could fill this gap along riparian areas by providing a mixed vegetative and wood buffer, providing shade and reducing runoff and erosion (Sovell et al. 2000).

1.3.5. Financial

Silvopasture can provide a diversified income for landowners through yearly livestock sales as well as periodic timber sales. Most economic analysis for silvopasture have been done on pine silvopasture systems in the southern United States (Garrett et al. 2004). These studies have shown that silvopasture is typically more economically beneficial than both pine plantations alone as well as livestock systems alone. However, the timber sales are highly dependent on the timber market in the region as well as the quality of the timber. Pine plantations are common in the southeast, and markets are often well established.

Chapter 1 Tables

Table 1.1. Intensity levels of rotational grazing compared (Undersander et al. 2014).

	Rotational	Management-intensive	High Density Grazing
Paddocks	4-7	8-80+	Infinite
Grazing (days)	7-14	0.5-5	0.1-1
Resting (days)	20-40	20-40+	30-180
Stocking (lb $acre^{-1}$)	5000-10,000	10,000 – 100,000	100,000-500,000+
Utilization	30-45%	50-70%	60-80%

Chapter 1 Figures

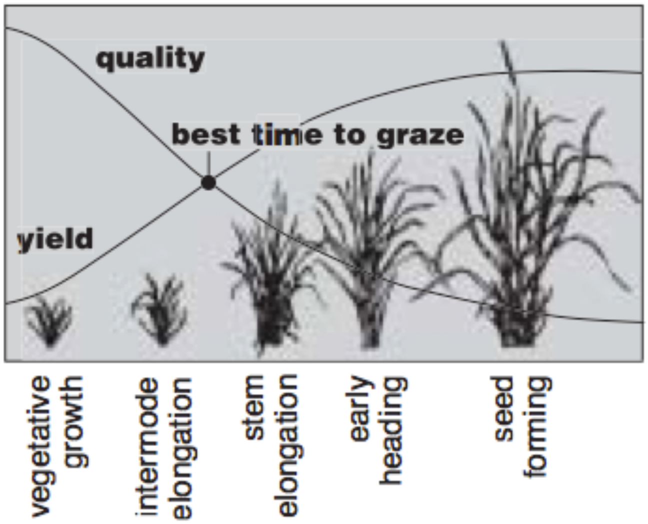


Figure 1.1 Forage quality and yield throughout plant growth (Undersander et al. 2014).

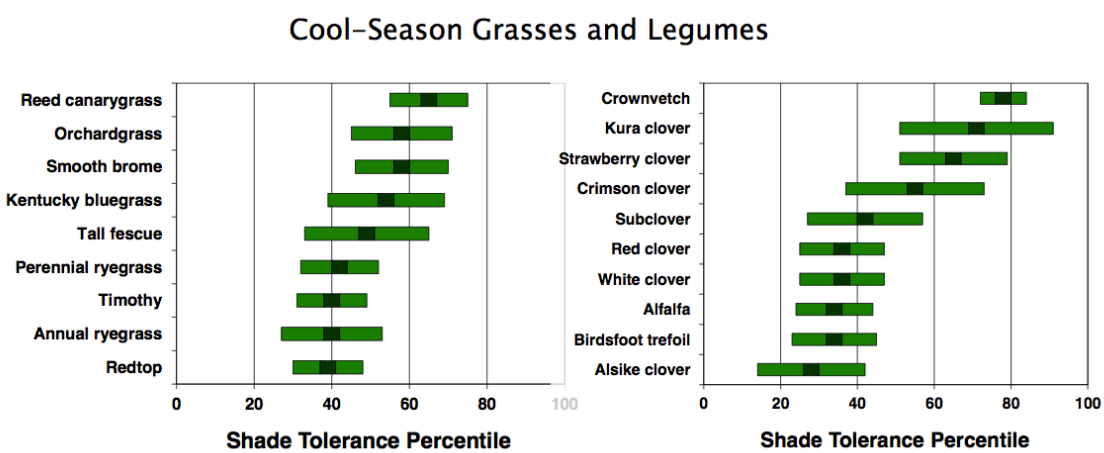


Figure 1.2. Shade tolerance of common forage species (legumes and cool-season grasses) (Walter 2015).

Chapter 2. Impact of managed woodland grazing on forage quantity, quality and livestock performance: the potential for silvopasture in Central Minnesota, USA

2.1. Synopsis

Over 300,000 ha of woodlands in Minnesota are grazed. Often these woodlands are not managed specifically for timber or cattle benefits. This lack of management often leads to decreased timber value and reduced forage yields. Silvopasture is a potential alternative to this lack of land management on Minnesota woodlots. Silvopasture is a type of agroforestry that intentionally combines trees, forage and livestock in an intensively-managed system. However, there are few known studies of silvopasture use in Minnesota. This three-year study (2013-2015) examines the potential for silvopasture success in Minnesota through the comparison of unmanaged woodland, silvopasture and open pasture sites. The study collaborated with three farmers in Central Minnesota to assess these three grazing systems on their land. Silvopasture paddocks were established through thinning and seeding woodland areas. The study assessed forage production, forage quality, livestock productivity, and species diversity. Forage production was typically greater in silvopasture systems compared to unmanaged woodlands, however forage quality was comparable between the three grazing systems. Additionally, biodiversity was typically lowest

in open pastures, and comparable between silvopasture and woodland areas. Livestock performance was similar between the grazing systems. Results indicate that silvopasture has potential in Minnesota, but more research is needed to develop specific management guidelines as well as monitor silvopasture for longer periods of time.

2.2. Introduction

Minnesota is an agricultural state with farms producing a variety of outputs including timber, corn, soybeans, wheat, alfalfa, and cattle (for beef and dairy). In Minnesota there are 6.8 million ha of forestland; of that 0.81 million ha are on farms and 37% of those are grazed (Garrett et al. 2004). There are 40,457 ha of land in Crow Wing county and 533 farms, of which 216 are cattle producing (NASS 2015). Woodlands on farms have been used for timber, fuel, fence posts, windbreaks, etc., but their production has rarely been optimized (Garrett et al. 2004). The grazing of forested land is a common practice in the United States on which there are varying opinions. Woodland grazing has undergone most recent scrutiny by DenUyl (1945) who argued that farm woodlands should not be grazed, and he argues that excluding livestock is the only appropriate management tool. Grazing in unmanaged woodlands has been shown to result in undesirable ecological changes, including the drying out of soils due to destruction of the protective humus and leaf litter (DenUyl 1945). Forage regrowth has been shown to be extremely low in unmanaged woodland grazing systems especially those with hardwood tree species (Johnson 1952). The trampling action in the soil can affect soil erosion and infiltration rates, as well as diameter growth of dominant trees, due to compaction of the upper six inches of the soil and killing of surface roots (Johnson 1952). Woodland grazing also has negative impacts on the watershed, causing increased magnitude of storm runoff and increased stream turbidity (Johnson 1952). Most grazed woodlands in Minnesota are not actively managed for timber (Demchik et al. 2005). DenUyl (1945) also claims that woodland grazing results in weight loss for cattle, and thus woodland grazing in Minnesota is likely not a productive use of the land. This lack of management is likely not only leading to decreased timber value, but also reduced forage yields (Demchik et al. 2005). However, with the use of intensive management techniques, trees, forage and livestock interactions can be manipulated to enhance productivity of woodlands (Lin et al. 1998; Garrett et al. 2004; Kallenbach et al. 2006). Agroforestry techniques have been used to balance the value for trees and livestock in these combined systems.

Agroforestry is defined by the Association for Temperate Agroforestry (AFTA 2016) as an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock. Silvopasture is one of the five basic types of agroforestry practices in North America, in which trees, forage plants and livestock are intentionally combined together as an integrated, intensively-managed system. Silvopasture aims to increase the economic value of the land through diversification of income as well as increase the environmental value of the land. Silvopasture has been studied around the world and a variety of benefits and challenges exist within these systems. Common benefits include timber sales, enhanced microclimate, fewer weeds, reduced forest fire, reduced animal stress, minimized soil erosion and diversified income (Nair et al. 1995; Kallenbach et al. 2006; Nair et al. 2007; Nair et al. 2009; Cubbage et al. 2012) . Shading provided by trees in Silvopasture systems can have positive benefits. Generally, cattle performance can improve with moderate shading (Cartwright 1955). Furthermore, it has been found that some C_3 cool season grasses actually perform better under shade environments than they do in the sun. Crude protein has also been shown to be higher in some species in shady environments, while forage digestibility does seem to be lower in shaded environments (Lin et al. 2001). Some challenges include the complex management required (and continued forest thinning), competition between forage and trees, trees falling onto fences, lack of timber market, the time required to establish, and initial economic investment (Cubbage et al. 2012).

There has been extensive research regarding Silvopasture in southeastern United States pine plantations (Grado et al. 2001; Kallenbach et al. 2006; Nair et al. 2007). However, there has been minimal research relating to hardwood silvopasture systems (Lehmkuhler et al. 2003). Additional research is needed to determine the potential for silvopasture use in Minnesota as well as establish region specific management guidelines.

This study aimed to determine the potential for silvopasture in Minnesota. Specific objectives were to:

1. Determine how silvopasture management influences annual forage production
2. Determine how silvopasture management influences forage nutritive quality and
3. Determine how silvopasture management influences animal performance.

2.3. Materials and Methods

2.3.1. Study Sites

The study was conducted in Cass and Crow Wing County in Central Minnesota with three individual farmer cooperators, their farm research sites are referred to as Booth (46°21’N, 94°22’W) , Caughey (46°11’N, 94°7’W), and Moe (46°11’N, 94°9’W). The soil present at the sites is summarized in **Table 2.1**. Average annual precipitation is 723 mm, with average mean average temperature of 4.8°C.

2.3.2. Systems and System Establishment

The study employed three systems:

1. open pasture systems representing conventional pasture without trees;

2. silvopasture systems representing the agroforestry practice of silvopasture by incorporating trees, forage and livestock in one intensively managed system;
3. woodland systems representing traditionally unmanaged grazing of farm woodlots.

Three paddocks covering 2.02 ha each were established at each site (Booth, Caughey, and Moe). Each paddock represented one of the three systems. The paddocks were fenced with high tensile fencing and connected to a solar panel charger or electric fencer to contain the experimental cows within the paddock. Except for the woodland that remained unmanaged, management techniques were applied and employed to the silvopasture and open pasture paddocks. Tree species varied by site, but most common were Paper Birch (*Betula papyrifera*), Bur Oak (*Quercus macrocarpa*), Red Oak (*Quercus rubra*), Red Maple (*Acer rubra*) and Quaking Aspen (*Populus tremuloides*) (**Table 2.2**).

Systems were established in Summer and Fall 2013. Thinning was employed in the silvopasture systems in Fall 2013 when the ground was frozen to avoid soil disturbance. Prior to thinning, a tree inventory was conducted to determine initial tree volume and to mark trees to be removed in order to achieve a basal area of 9.2 to 10.3 m^2 ha^{-1}. This basal area was determined to be appropriate for the study and for the study sites. Table 2.3 presents the project sites' initial and final conditions. A mix of 1.13 kg timothy (*Phleum pratense*) and 2.7 kg red clover (*Trifolium pretense*) were applied to the 0.4 ha open pasture and silvopasture paddocks in late fall 2013 when the ground was frozen. Prior to seeding, a soil test was conducted at all sites to determine soil nutrient status and to adjust fertility of the soil. Based on soil nutrient analysis, the silvopasture and open pasture paddocks were fertilized with urea 46-00-00 and potash 00-00-60 based on the recommendation of the University of Minnesota Soil Analytical Lab. In Winter 2014, the silvopasture and open pasture paddocks were over-seeded with native grasses including slender wheatgrass (*Agropyron trachycaulum*)(2.24 kg ha^{-1}), fringed brome (*Bromus ciliates*)(2.24 kg ha^{-1}), and Virginia wild rye (*Elymus virginicus*)(4.48 kg ha^{-1}), to increase native grass presence in the pastures.

2.3.3. Grazing Management

Four cow-calf pairs were assigned to each system paddock each year; pairs differed between years. Grazing began each spring when forage height averaged 20 cm (25 June 2014; 11 June 2015). Grazing continued until any paddock reached an average forage height of 7-10 cm (an average of 20 days in 2014; 15 days in 2015). A fallow period occurred after each introduction to allow for forage regrowth; cow-calf pairs were re-introduced into paddocks when forage reached an average of 20cm in height (late July to early August). All systems at each site received the same grazing management and timing. The grazing season ended in late August/early September. Cattle had full access to the 2.02-ha paddocks for the two 15-day grazing periods each growing season in 2014 (**Table 2.4**) and 2015 (**Table 2.5**).

2.3.4. Forage quantity & quality assessments

Forage quantity was determined both for 2014 and 2015 growing seasons. Biomass samples were collected three times each growing season (early, mid, and late seasons) to determine availability of biomass throughout the growing season. Biomass was collected before cattle were introduced: early(May/June), mid(July/August), and late(September/October). Biomass was collected and assessed from five random samples in each 2.02 ha paddock. Each sample was collected by clipping the forage inside the m^2 plot to a height of 5 cm using garden sheers. Clippings were collected and oven-dried at a constant temperature (70°C) for 5 days and then weighed to determine dry weight per hectare.

After weighing, a composite sample (composed of the five samples from each paddock) was transferred to a 16.5 x 14.9 cm plastic bag and sent to Stearns County DHIA laboratories for forage quality testing. Forage was analyzed for percent crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), Non-Fiber Carbohydrates (NFC), total digestible nutrients (TDN) and relative feed value (RFV). CP is determined by the amount of nitrogen in the sample; higher CP generally means higher quality feed. ADF represents amount of cellulose and lignin in the plant, and is a measure of digestibility, therefore lower ADF is higher quality. NDF consists of the cell wall contents as well as the ADF and is used to predict intake; as NDF increase, intake is expected to decline. TDN is an estimate of the energy content calculated using ADF, NDF, CP and ash components, and increases with higher quality feed. NFC includes carbohydrates such as sugars and starches that can be broken down by animal enzymes, and increases with higher quality feed. RFV is an index of forage quality based on digestible dry matter and dry matter intake.

Remaining (after sample was sent to lab) combined forage samples were visually analyzed for maturity level (on a scale from 0-10, 10 being completely headed out, and 0 having no signs of flowering), and percent forbs for each system, during each season at each site for each year separately.

2.3.5. Livestock performance measurement

The total number of grazing days (**Table 2.4** and **Table 2.5**) was recorded and calculated for each grazing period. Cows and calves were weighed before and after each grazing period [only cows (not calves) were weighed in 2014]. Average daily gain (ADG) was calculated for each individual animal by dividing total weight gain in each introduction by the number of grazing days in that introduction period. Weight change for each cow for the full growing season (total daily gain) was calculating by subtracting the initial weight for the first introduction from the final weight for the second introduction.

2.3.6. Weather

Weather data, primarily precipitation and temperature, was obtained from the historical weather data from the Brainerd-Crow Wing County Regional Airport weather station (46°23'N, 94°08'W) obtained from Weather Underground (wunderground.com).

2.3.7. Data Analysis

Data were also analyzed according to year due to changes in environmental conditions each year causing significant interaction effects. Analysis of variance (ANOVA) was conducted to analyze system, site and season effects. Main effects and all interactions were considered significant at $\alpha < 0.05$. Tukey's HSD was used to determine pairwise differences. Pearson's product-moment correlation coefficient was used to test for correlation. All analyses were done in R 3.2.3 (R Core Team 2016) and graphs were made using the ggplot2 package (Wickham 2009).

2.4. Results

2.4.1. Forage Production

Forage mass increased with decreasing tree density in 2014; forage mass from open pasture systems was 57% greater ($p<0.001$) than from silvopasture systems and 110% greater ($p<0.001$) than from woodland systems. Forage mass from silvopasture systems was 34% greater ($p=0.048$) than from woodland systems in 2014 (**Table 2.6**). In 2014, the open pasture system produced significantly more forage in the mid season compared to the early and late seasons ($p<0.05$), while the woodland system produced significantly less in the early season than the mid and late seasons ($p<0.05$), and no significant variation across seasons was observed in the silvopasture system (**Table 2.6**). During the early season in 2014, the woodland system produced significantly less than the open pasture and silvopasture systems ($p<0.05$), while during the mid season the open pasture system produced significantly more than both the silvopasture and woodland systems ($p<0.05$) (**Table 2.7**). No significant system variation was detected during the late season (**Table 2.7**). A significant season x system interaction ($p<0.05$) reveals that forage production in woodland systems increased from the mid-season to the late-season, while forage production in open pasture and silvopasture systems decreased from the mid-season to the late season. The magnitude of these system differences within sites influenced the observed site x system interaction ($p<0.001$); **Figure 2.1** demonstrates that in 2014 the same system pattern existed within each site revealing that forage production was highest in open pasture systems followed by silvopasture and then woodland systems at each site.

In 2015, silvopasture and open pasture systems outperformed woodland systems in terms of forage production (**Table 2.6**). Forage mass from woodland systems was 29% lower ($p<0.05$) than from open pasture systems, and 52% lower ($p<0.01$) than from silvopasture systems (**Table 2.6**). The open pasture and woodland systems produced significantly more forage in the mid season in 2015 ($p<0.05$), while seasonal variations in the silvopasture system were not significantly different (**Table 2.6**). In 2015, during the mid season, the silvopasture system produced significantly more forage than both the open pasture and woodland systems ($p<0.05$) (**Table 2.7**). Site differences were observed in 2015 through the site x system interaction ($p<0.001$). **Figure 2.1** demonstrates that in 2015 system trends were similar at Booth's site and Caughey's site where silvopasture systems had the highest forage production, but the pattern was different at Moe's site where the open pasture system had the highest forage production.

2.4.2. Forage Quality

In 2014, forage nutritional value was lower at Moe's site than Booth's and Caughey's [CP($p<0.05$), ADF($p<0.05$), NDF($p<0.01$), TDN($p<0.05$), NFC($p<0.05$), RFV($p<0.01$)] (**Table 2.8**). In general, nutritional value was higher in woodland systems than open pasture systems [RFV($p<0.05$), NFC($p<0.01$), NDF($p<0.01$)] (**Table 2.8**). Site x system interactions reveal that nutritional value (ADF, TDN, RFV) at Booth's site was higher under the silvopasture system than the open pasture and woodland systems, while at Caughey's site the nutritional value of the silvopasture system was lower than the open pasture and woodland systems. At Moe's site the woodland system had the highest nutritional value followed by the silvopasture system and then the open pasture system (**Figure 2.2**).

In 2015 there were no significant system differences observed, but differences in nutritional value were seen through seasonal effects. The nutritional value during the mid-season was lower than that during the early season (CP($p=0.1$), ADF($p<0.01$), NDF($p<-0.05$), TDN($p<0.01$), RFV ($p<0.05$)) (**Table 2.9**). In general nutritional value was lower at Moe's site than at Caughey's site (NDF($p<0.01$), RFV($p<0.05$)).

Maturity analysis showed that grass maturity was negatively correlated with CP($p<0.04$, $r^2=-0.28$), RFV($p<0.01$, $r^2=-0.38$), TDN($p<0.05$, $r^2=-0.28$) and NFC($p<0.01$, $r^2=-0.43$), and positively correlated with ADF($p<0.05$, $r^2=0.28$) and NDF($p<0.001$, $r^2=0.47$). The percent of forbs was also positively associated with CP ($p<0.01$, $r^2=0.415$). Woodland systems were nutritionally superior (in 2014) due to a decreased grass maturity as well as higher percent forbs compared to open pasture systems.

2.4.3. Livestock Performance

Total daily gain for cows, across years, was higher in open pasture systems than in woodland systems ($p<0.05$), and marginally higher in silvopasture systems than in woodland systems ($p=0.2$). The total daily gain for cow's at Caughey's site was lower than at Moe's site ($p<0.001$), and Booth's site ($p<0.01$) across years.

In 2014, ADG for cows was higher during the first introduction than the second introduction ($p<0.01$). Site differences were revealed through the site x introduction interaction ($p<0.01$).

In 2015, ADG for cows was higher during the second introduction than the first introduction ($p<0.01$). Site differences were revealed through the site x introduction interaction ($p<0.001$) which showed that cows at Caughey's site had the lowest ADG during the first introduction, but the highest ADG during the second introduction. The system x introduction interaction in 2015 ($p<0.01$) reveals that the woodland systems was largely responsible for introduction differences. While the cow's ADG in open pasture and silvopasture systems remained relatively constant across the two introductions, the ADG of cows in the woodland systems was negative during the first introduction and positive during the second introduction.

2.5. Discussion

2.5.1. Forage production

Lower forage production in the woodland system compared to the open pasture and silvopasture systems was expected due to the increased abundance of trees, translating to lower light transmission to forest floor, and resulting competition for growth resources (Sharrow 1998). Forage production was significantly higher in 2014 than 2015 ($p<0.001$), which can be attributed to weather differences, primarily significantly more precipitation in 2014 than 2015 (p<0.001). **Table 2.10** summarizes total monthly precipitation for 2014 and 2015. Rainfall was also significantly correlated with forage mass ($p<0.01$, $r^2=0.502$) for both years. The greater forage production in 2014 in the open pasture system was not surprising as the area received full-sunlight, as also observed by Silva-Pando et al. (2002) and Kallenbach and Kerley (2006) in their studies in Spain and Missouri, respectively.

In 2015 the lack of significant difference between open pasture and silvopasture systems on forage production demonstrates that silvopasture systems can be comparable with open pasture systems, which is likely due to microclimatic conditions that can lead to more consistent temperature, moisture, and light transmission that favor forage production under such condition (Silva-Pando et al. 2002; Kallenbach et al. 2006). These microclimatic conditions are even more substantial and beneficial during times of drought when open pasture systems are more likely to suffer due to higher evapotranspiration rates, as was observed during 2015 (Holechek et al. 1981; Frost and McDougald 1989; Buergler 2004) (**Table 2.10**). In 2015 differences between sites, specifically the higher forage production in the woodland system at Moe's site was higher than the silvopasture system. This can be explained by the increased grazing pressure in the silvopasture system at Moe's site, because eight cow-calf pairs were introduced to the silvopasture system and no cow-calf pairs were introduced to the woodland system for both introductions due to fence malfunction (**Table 2.5** and **Figure 2.1**).

The difference in forage production between 2014 and 2015 could be attributed to the additional time for silvopasture system establishment, and to changes in weather. In 2014 there was significantly more rainfall than in 2015 which would account for the lower forage production in 2015. Additionally, the silvopasture had higher forage production revealing that silvopasture systems might outperform open pasture systems in times of drought. The declining forage production throughout the growing season in 2015 also shows the effects of the drought as precipitation decreased and temperature increased during the study period.

Seasonal differences can be partially explained by the positive correlation between total rainfall (cm) during that season and forage mass ($p<0.01$, $r^2=0.502$). Holechek et al. (1981) also found that rainfall and temperature changes throughout the growing season effect forage production, and can effect systems differently. Holechek et al. (1981) therefore suggests that open pasture and silvopasture systems should be used at different times throughout the growing season as part of the grazing plan in order to maximize land use. In this study both open pasture and silvopasture systems did best during the mid-season in 2014. While in 2015, the silvopasture did better than the open pasture in the mid- season, which corroborates Holechek et al.'s (1981) findings that livestock should be moved to silvopasture systems in mid to late summer.

2.5.2. Forage quality

Forage nutritive value was often higher in the woodland system, which agrees with the findings of Lin et al. (2001) who found that increased shade levels tend to increase CP content as well as decrease ADF and NDF (Buergler et al. 2006). Significant quality differences between sites in both years indicates that site characteristics might play a larger role in forage nutritive value than system differences. While these differences were not specifically measured in this study they might include local weather differences, past management including seeding and grazing pressure, and actual light availability. We were not able to measure actual light availability or photosynthetic production differences at each site, but differences in tree spacing at each site could have impacted light availability and therefore growth rate and maturity level.

Average mean temperature and minimum temperature were significantly higher in 2014 than 2015 ($p<0.01$ and $p<0.001$ respectively) and average maximum temperature was significantly correlated with CP ($p<0.05$, $r^2=0.434$), NDF ($p<0.05$, $r^2=-0.44$), revealing that higher temperatures can result in higher protein and intake. Average minimum temperature was negatively correlated with TDN ($P<0.05$, $r^2=-0.43$), revealing that low temperatures can result in higher TDN or digestible nutrients, because lower maturity is associated with lower temperatures and higher digestibility. **Figure 2.3** summarizes minimum and maximum temperature throughout the growing season in 2014 and 2015.

Site x system interactions in 2014 are likely due to differences in botanical composition between systems at each site. The woodland system at Booth's site had more shrubs, specifically raspberry (*Rubus spp.*), while the silvopasture system had more grasses and forbs, which could explain the increased digestibility (TDN and ADF) in the silvopasture system. Additionally, the open pasture system at Booth's site was highly unproductive resulting in low vegetative growth, rendering it less digestible, compared to the other systems at Booth's site The lower digestibility in the silvopasture system at Caughey's site could be attributed to higher maturity due to faster regrowth as well as ideal growing conditions due to partial shading and high amounts of precipitation. The woodland system at Caughey's site also had more herbaceous forbs than grasses which can result in higher quality due to increased digestibility compared to mature grasses. These differences in botanical composition are likely due to differences in past management such as grazing pressure.

Lack of significant system differences for all measures of forage nutritive value in 2015 might be due to slower forage growth and therefore a lower maturity level due to low precipitation levels in 2015 than 2014 (Table 2.10). However, the stronger seasonal differences seen in 2015 compared to 2014 reveal precipitation might have influenced maturity of the forages as quality was highest in the early season when rainfall was highest compared to the mid-season when rainfall and quality were lower.

The forage quality in the silvopasture system was higher than the open pasture and the woodland systems. This is not surprising as cool-season grasses grown under partial shade have been shown to outperform (in terms of quality) those grown in full sun (Kallenbach et al. 2006).

Changes across seasons show that each system has its own strengths in different seasons and rotating these systems throughout the growing season might result in the most productive use of the land (Holechek et al. 1981). For example, Booth's site in 2015, the woodland had the highest percent CP in the early season, the silvopasture had the highest in the mid-season and open systems had the highest in the late season.

2.5.3. Livestock Performance

Differences between years can be attributed to differences in rain and temperature as total rainfall was greater in 2014 than 2015 ($p<0.001$), and in 2015 rainfall was greater during the first introduction than the second introduction ($p<0.01$)(**Table 2.10**). There was also a positive correlation between mean temperature and ADG ($p<0.01$, $r^2=0.55$).

With the exception of the open pasture system at Caughey's and Moe's in 2014 and the silvopasture system at Booth's in 2015, negative ADG of cows can be explained by overstocking, or too many actual pasture days (**Table 2.11** and **Table 2.12**).

This study does not detect any significant effect between system types on cattle weight. This is consistent with the findings from Holechek et al. (1981) and Kallenbach and Kerley (2006), and might be due to the short period of this study or the small number of cattle for each paddock. Livestock performance decreases over time in silvopasture pastures as tree canopies close, however if silvopasture systems are managed to maintain a consistent basal area (and shade cover) then we would not expect this to occur (Hawke 1991). This lack of difference could also show that even though forage production was higher in open pastures, the cattle in the silvopasture did not suffer in performance. This could be due to the higher quality in silvopasture forage or the increased protection from wind and heat provided by the trees (Cartwright 1955; McArthur 1991). Cow weight gain is expected to fluctuate some, especially postpartum, however we expected calf weights to increase. The lack of evidence for difference between systems and calf weight gain, likely suggests that systems were not different enough to impact livestock performance. The relationship between cow weight gain and rainfall suggests that there are a large number of factors affecting livestock performance besides those measured in this study (forage production and forage quality). While weather might have been an additional factor, protection and shading also were not tested separately. It was also observed by the landowners that livestock might have been stressed due to herd separation, which could not be accounted for in this study.

2.6. Conclusions

Beef producers in central Minnesota can employ silvopasture practices on unmanaged woodlands to improve land use of marginal lands. Forage in woodlands is generally lower in quantity than open pasture and silvopasture systems. Forage quality is more variable than quantity, but silvopasture systems often have higher quality than open pasture, especially during certain seasons. Most landowners will not convert all grazing lands to silvopasture and therefore rotating livestock through silvopasture paddocks when open pastures are low in quantity or quality can provide an additional source of forage to livestock at various times throughout the year. As livestock performance does not vary significantly between these three systems, landowners can manage their woodlands as silvopasture systems (and thus increasing total grazing lands) without sacrificing livestock health.

More research needs to be done to determine the long term effects of trees in these silvopasture systems, and how stocking rates should be adjusted to best suit a silvopasture system and reduce tree damage.

Chapter 2 Tables

Table 2.1. Summary of soil characteristics of each paddock at each site.

Site	Soil Types	Slope	pH	Soil Texture
Booth				
Open Pasture	DeMontreville-Mahtomedi-Cushing complex	0-40%	5.6	Coarse
	Sandwick loamy sand			
Silvopasture	DeMontreville-Mahtomedi- Cushing complex	2-40%	5.1	Coarse
	Cushing loam			
	Alstad fine sandy loam			
Woodland	DeMontreville-Mahtomedi- Cushing complex	3-40%	5.3	Medium
	Warba very fine sandy laom			
Caughey				
Open Pasture	Chetek-Seelyeville ponded complex	0-15%	5.7	Coarse
Silvopasture	Nokay-Prebish complex	0-15%	5.4	Coarse
	Chetek-Seelyeville ponded complex			
Woodland	Chetek-Graycalm complex	0-15%	5.4	Coarse
Moe				
Open Pasture	Bushville loamy sand	0-4%	5.3	Coarse
	Brainerd sandy loam			
Silvopasture	Chetek-Graycalm complex	6-12%	5.3	Coarse
Woodland	Chetek-Graycalm complex	0-6%	5.3	Coarse

Table 2.2. Common tree species found in each silvopasture system. Species are expected to be similar in woodland systems at the same site.

Booth	Caughey	Moe
Betula papyrifera	*Populus tremuloides*	*Pinus banksiana*
Quercus rubra	*Acer Rubrum*	*Betula papyrifera*
Acer rubrum	*Quercus macrocarpa*	*Quercus macrocarpa*
Prunus serotina	*Populus balsamifera*	*Quercus rubra*
Populus tremuloides	*Ulmus americana*	
Ulmus Americana	*Prunus serotina*	
Fraxinus pennsylvanica		

Table 2.3. Summary of system establishment and management occurring from summer 2013 to spring 2014.

System	Initial Condition	Management Actions	Final Condition
Woodland	BA= 16-18 $m^2\ ha^{-1}$ Average DBH= 30cm	None	BA= 16-18 $m^2\ ha^{-1}$
Silvopasture	BA= 16-18 $m^2\ ha^{-1}$ Average DBH= 30cm	Thinning Broadcast Seeding Fertilization	BA=9.2-10.3 $m^2\ ha^{-1}$
Open pasture	BA=0-0.5 $m^2\ ha^{-1}$	Broadcast seeding Fertilization	BA=0-0.5 $m^2\ ha^{-1}$

Table 2.4. Cow introduction dates and total pasture and fallow days for 2014.

2014		Introduction 1 Dates				Introduction 2 Dates			
	Cow-Calf Paris	Introduction	Removal	Total Days 1	Total Days Fallow	Introduction	Removal	Total Days 2	Total Pasture Days
Booth									
Open Pasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Silvopasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Woodland	4	25-Jun	14-Jul	19					21
Caughey									
Open Pasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Silvopasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Woodland	4	25-Jun	14-Jul	19					21
Moe									
Open Pasture	4	24-Jun	5-Jul	11	39	13-Aug	10-Sep	28	39
Silvopasture	4	24-Jun	5-Jul	11	39	13-Aug	10-Sep	28	39
Woodland	4	24-Jun	5-Jul	11					11

Table 2.5. Cow introduction dates and total pasture and fallow days for 2015.

2015		Introduction 1 Dates				Introduction 2 Dates			
	Cow-Calf Paris	Introduction	Removal	Total Days 1	Total Days Fallow	Introduction	Removal	Total Days 2	Total Pasture Days
Booth									
Open Pasture	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Silvopasture	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Woodland	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Caughey									
Open Pasture	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Silvopasture	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Woodland	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Moe									
Open Pasture	4	8-Jun	20-Jun	12	60	19-Aug	2-Sep	14	26
Silvopasture	8	8-Jun	20-Jun	12	60	19-Aug	2-Sep	14	26
Woodland	0								

Table 2.6. Biomass production in 2014 and 2015 showing system variation within each season. Different letters in each column show significant differences within a season and averaged across all seasons ($p<0.05$).

	2014				2015			
	Early	Mid	Late	**Average**	Early	Mid	Late	**Average**
Open Pasture	1261a	1961 a	1267a	**1526 a**	641 a	394 b	479 a	**505 b**
Silvopasture	932 a	1030 b	935 a	**968 b**	632 a	573 a	429 a	**545 b**
Woodland	550 b	863 b	892 a	**724 c**	482 a	310 b	282 a	**358 a**

Table 2.7. Biomass production in 2014 and 2015 showing seasonal variation within each system. Different letters in each row show significant differences within a system, by year ($p<0.05$).

	2014			2015		
	Early	Mid	Late	Early	Mid	Late
Open Pasture	1261 a	1961 b	1267 a	641 a	394 b	479 ab
Silvopasture	932 a	1030 a	935 a	632 a	573 a	429 a
Woodland	550 a	863 b	892 b	482 a	310 ab	282 b

Table 2.8. Nutritive quality standards in 2014 for system differences (open pasture, silvopasture and woodland) and site differences (Booth, Caughey and Moe). Means with different letters are significantly different (p<0.05).

	System			Site		
	Open Pasture	Silvopasture	Woodland	Booth	Caughey	Moe
CP	9.72 a	10.88 a	11.08 a	11.43 a	11.41 b	8.84 b
ADF	42.91 a	41.59 a	40.86 a	41.11 a	39.43 b	44.81 b
NDF	65.88 b	61.97 ab	58.65 a	60.45 a	58.98 b	67.07 b
TDN	53.62 a	54.29 a	55.96 a	55.67 a	56.75 b	51.45 b
NFC	13.07 b	15.11 b	18.95 a	16.79 a	17.57 b	12.77 b
RFV	79.37 b	84.52 ab	91.08 a	88.07 a	91.01 b	75.88 b

Table 2.9. Nutritive quality standards in 2015 for early, mid and late seasons. Means with different letters are significantly different (p<0.05).

	Early	Mid	Late
CP	12.51 a	10.28 a	12.6 a
ADF	37.28 a	41.22 b	39.66 ab
NDF	59.83 a	63.28 b	61.00 ab
TDN	60.39 a	55.55 b	57.22 ab
NFC	16.97 a	16.38 a	14.7 a
RFV	94.01 a	83.55 b	88.83 ab

Table 2.10. Total precipitation (cm) during each month in the study period for 2014 and 2015.

	Total Precipitation (cm)	
	2014	2015
April	3.7	1.6
May	231.6	10.5
June	10.7	2.1
July	5.5	7.4
August	14.4	5.1

Table 2.11. Summary of grazing parameters including cow and calf ADG for 2014.

	2014								
	Booth			Caughey			Moe		
Introduction	Open Pasture	Silvopasture	Woodland	Open Pasture	Silvopasture	Woodland	Open Pasture	Silvopasture	Woodland
1									
Stocking (kg/ha)	1439	1432	1524	2024	1928	1800	1555	1634	1838
Actual pasture days	19	19	19	19	19	19	11	11	11
ADG, cows	0.60	0.80	0.23	0.87	1.52	0.90	1.49	0.41	1.24
ADG, calves	--	--	--	1.45	1.12	1.37	--	--	--
Calculated pasture days	19.58	18.06	10.05	18.42	10.24	8.75	23.51	13.55	7.64
*Stocking Ratio	1.24	1.30	0.73	1.29	0.73	0.42	2.51	1.75	0.99
2									
Stocking (kg/ha)	1442	1398	--	2086	1963	--	1684	1685	--
Actual pasture days	21	21	--	21	21	--	28	28	--
ADG, cows	1.37	0.52	--	-1.48	-1.16	--	-0.12	-0.34	--
ADG, calves	--	--	--	--	--	--	--	--	--
Calculated pasture days	24.20	17.95	--	31.41	8.88	--	34.71	19.07	--
*Stocking Ratio	1.40	1.14	--	2.00	0.57	--	1.35	0.95	--

* stocking ratio indicates over- or under- stocking. Numbers below 1 are overstocked and above 1 are understocked.

Table 2.12. Summary of grazing parameters including cow and calf ADG for 2015.

	2015								
	Booth			Caughey			Moe		
Introduction	Open Pasture	Silvopasture	Woodland	Open Pasture	Silvopasture	Woodland	Open Pasture	Silvopasture	Woodland
1									
Stocking (kg/ha)	1418	1202	1427	2147	2003	2023	1854	3718	--
Actual pasture days	19	19	19	19	19	19	12	12	--
ADG, cows	0.76	0.31	-0.27	-0.54	-0.27	-1.79	0.22	0.23	--
ADG, calves	0.561	0.27625	0.43425	- 1.33325	-1.271	-1.35425	2.386	2.184	--
Calculated pasture days	7.22	13.24	11.16	9.22	8.03	5.38	8.27	10.37	--
*Stocking Ratio	0.53	0.95	0.79	0.66	0.51	0.35	1.03	0.49	--
1									
Stocking (kg/ha)	1484	1271	1496	2107	1944	1978	2022	3856	--
Actual pasture days	12	12	12	15	15	15	14	14	--
ADG, cows	-0.64	-0.34	0.26	1.36	0.89	1.71	0.16	0.04	--
ADG, calves	2.46	-2.48	-3.57	-3.10	1.46	1.56	-0.18	-0.13	--
Calculated pasture days	3.07	12.38	5.71	3.86	11.19	3.46	7.20	4.52	--
*Stocking Ratio	0.35	1.42	0.63	0.36	0.90	0.29	0.77	0.18	--

* stocking ratio indicates over- or under- stocking. Numbers below 1 are overstocked and above 1 are understocked.

Chapter 2 Figures

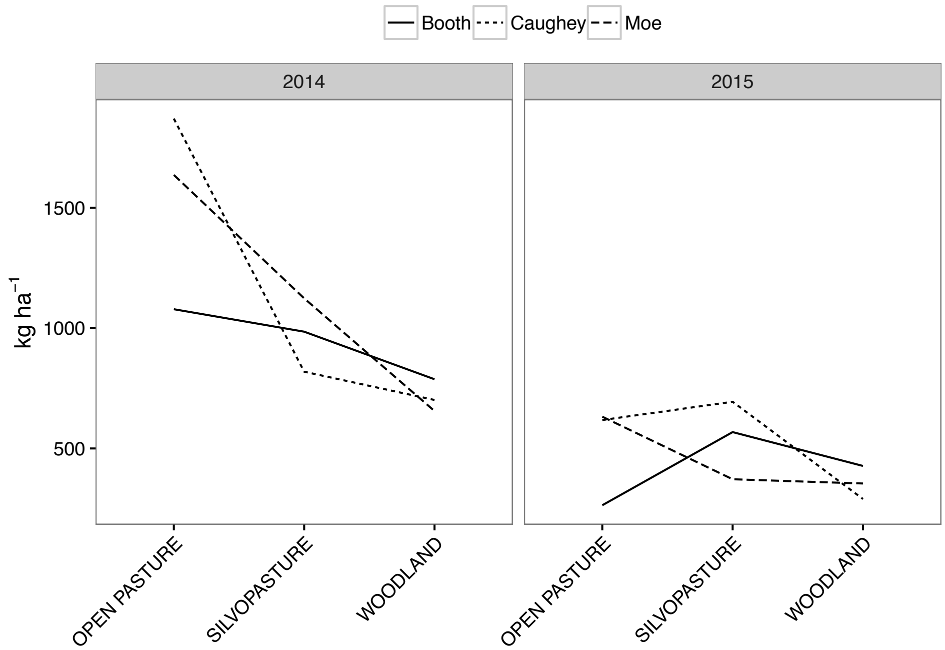


Figure 2.1. Site (Booth, Caughey and Moe) x system (open pasture, silvopasture and woodland) interaction ($p<0.001$) for forage mass (kg ha^{-1}) in 2014 and 2015.

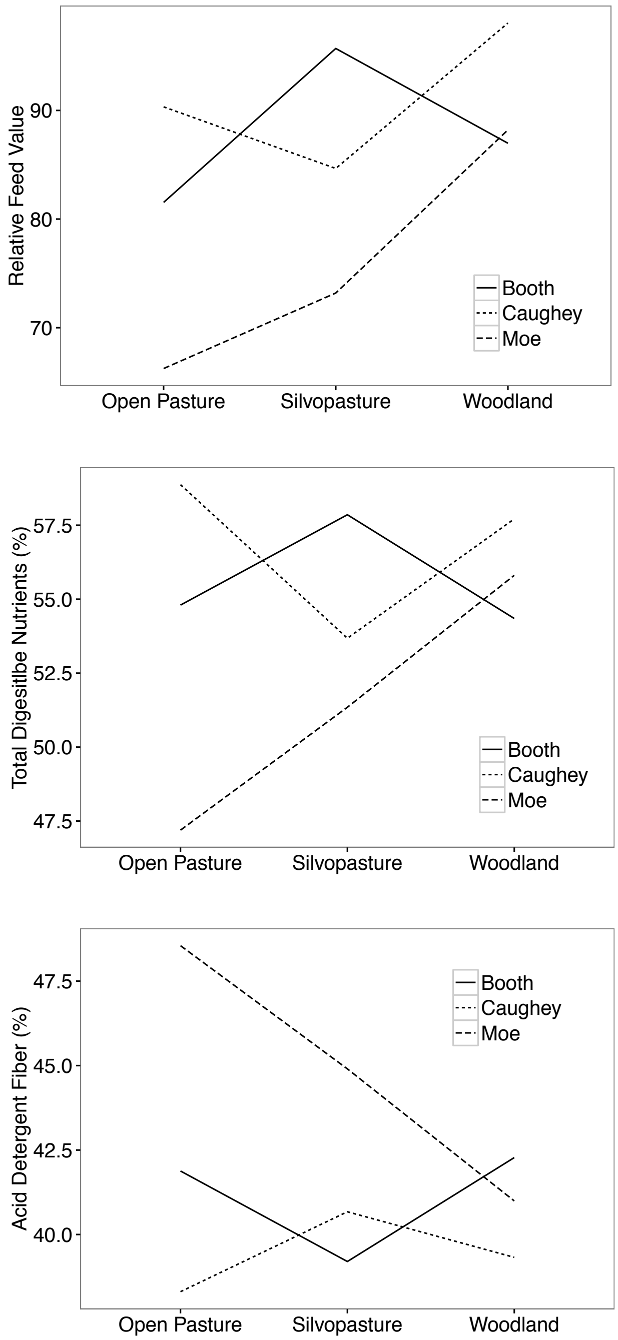


Figure 2.2. Site (Booth, Caughey, Moe) x system (open pasture, silvopasture woodland) interaction for Relative Feed Value (RFV), Total Digestible Nutrients (TDN), and Acid Detergent Fiber (ADF).

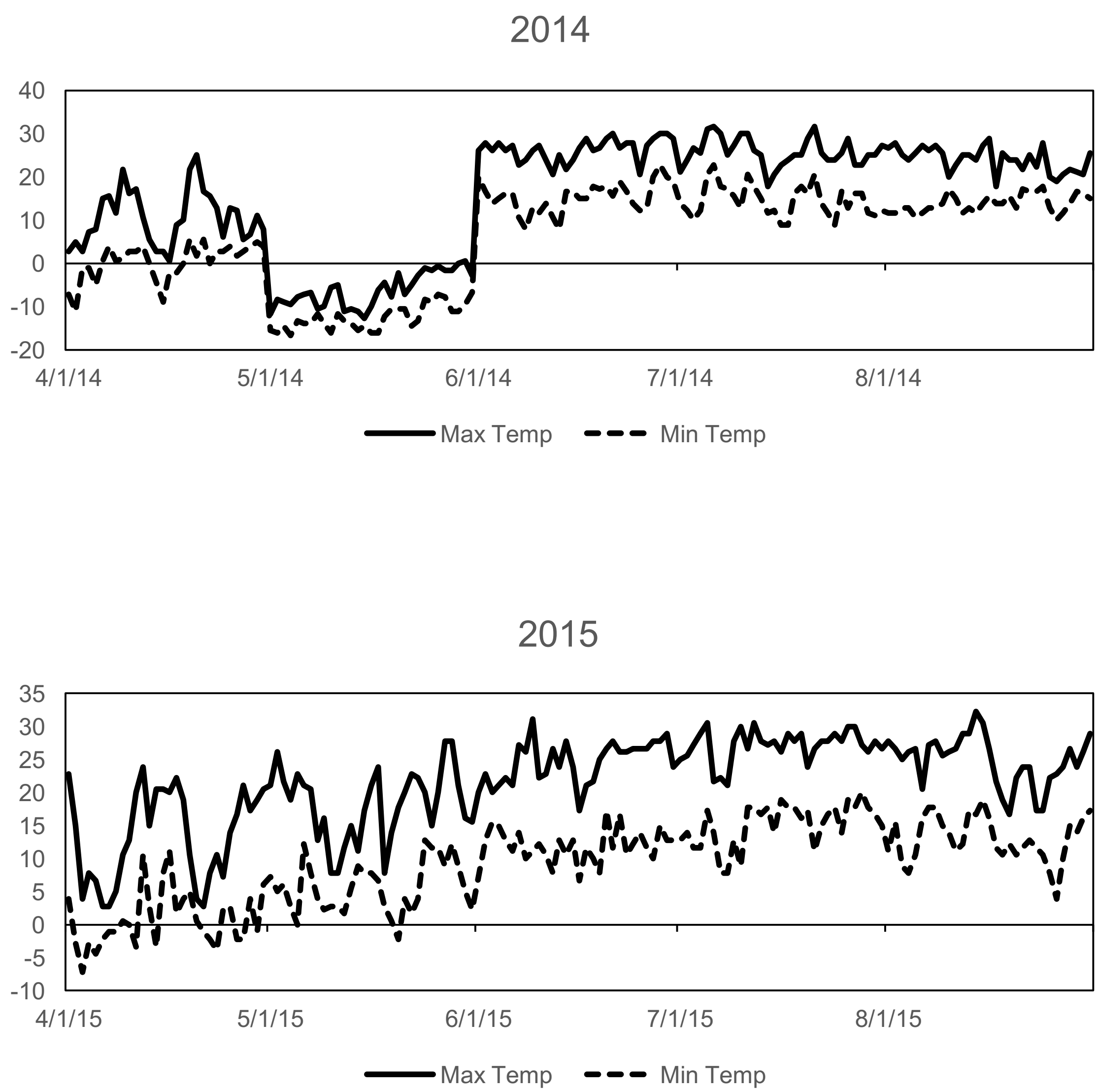


Figure 2.3. Daily maximum and minimum air temperatures (°C) at Brainerd-Crow Wing County Regional airport during forage growth periods for 2014 (top panel) and 2015 (bottom panel).

Chapter 3. Environmental impacts of silvopasture management in Central Minnesota, USA: species diversity and soil health

3.1. Synopsis

The environmental impacts of silvopasture management are poorly understood. Silvopasture is just starting to be explored in Minnesota and little research has gone into identifying the environmental benefits of this management practice. We compared species diversity, species richness and soil health in open pasture, silvopasture and woodland systems in central Minnesota. Open pasture and silvopasture systems were fertilized and broadcast seeded, while woodland systems remained unmanaged. Species richness and diversity were highest in woodland systems, followed by silvopasture systems. Soil health was higher in silvopasture systems and woodland systems than the open pasture system as well.

3.2. Introduction

Agricultural intensification in the Midwest United States has led to environmental degradation such as reduced soil health, reduced water quality and hypoxia in the Gulf of Mexico (Goolsby et al. 1999). As this degradation becomes increasingly harmful to ecosystem and human health, a search for alternative agriculture systems has become more pressing. Agroforestry systems have long been seen as integrated systems that increase yields while improving environmental function by mimicking natural systems. Silvopasture, a type of agroforestry, takes advantage of the interactions that exist between trees, forage and livestock, to increase yields, diversify income and improve environmental quality.

It has widely been observed that soil structure under forests are high in quality including high stability, low detachability and high infiltration capacity, therefore it is therefore expected that silvopasture systems will retain these benefits (Nair 1993). Additionally, canopy coverage and the resulting microclimate has also been shown to increase soil nutrients through increased litter quality and decomposition rates, resulting in higher amounts of organic matter (Tripathi et al. 2013). Increased forage production in silvopasture systems compared to woodland sites can also lead to increased soil organic matter (Sharrow and Ismail 2004). Due to improved soil health and structure, agroforestry systems have the added benefit of improving water quality by increasing infiltration capacity, and decreasing erosion and runoff, which reduce the addition of nutrients and sediment to water bodies (Sharrow 1998).

As a system that mimics a natural savanna ecosystem, silvopasture systems have the potential to improve forage species diversity and richness compared to woodland systems over time (Holechek et al. 1981). Silvopasture systems also increase fauna diversity by attracting species whose habitats include both woodland and prairie systems (Mcadam et al. 2007).

While woodland grazing is a common practice throughout the United States, there is a large potential to increase the productivity of these systems using silvopasture as a management tool. In Minnesota, USA alone there are 300,00 ha of forested land that is grazed (Demchik et al. 2005). Unmanaged woodland grazing has been linked to environmental degradation including soil erosion and water turbidity due to overgrazing (Johnson 1952). However, the addition of trees to an agricultural system has many positive environmental benefits compared to conventional open pasture systems (Garrett et al. 2004). Silvopasture can be viewed as a compromise between these two systems by enhancing productivity to that close to an open pasture system and maintaining environmental benefits associated with woodlands. Through the use of silvopasture management systems, the possibility of negative effects that can be associated with unmanaged woodland grazing such as soil erosion, soil compaction, tree damage and overstocking is decreased (DenUyl 1945).

The focus of this study was to monitor species diversity and richness as well as soil health in three systems: open pasture, silvopasture, and woodland. We predicted higher species diversity and richness in silvopasture systems compared with open pasture systems and similar species diversity and richness compared to woodland systems. We also expected improved soil health in the silvopasture and woodland systems compared to the open pasture system due to microclimatic conditions and the presence of trees.

3.3. Materials Methods

3.3.1. *Study Sites*

The study was conducted in Cass and Crow Wing County in Central Minnesota with three individual farmer cooperators, their farm research sites are referred to as Booth (46°21'N 94°22'W) , Caughey (46°11'N, 94°7'W), and Moe (46°11'N, 94°9'W). The soil present at the sites is summarized in **Table 3.1**. Average annual precipitation is 723 mm, with average mean average temperature of 4.8°C.

3.3.2. *Systems and System Establishment*

The study employed three systems:

1. open pasture systems representing conventional pasture without trees;
2. silvopasture systems representing the agroforestry practice of silvopasture by incorporating trees, forage and livestock in one intensively managed system;
3. woodland systems representing traditionally unmanaged grazing of farm woodlots.

Three paddocks covering 2.02 ha each were established at each site (Booth, Caughey, and Moe). Each paddock represented one of the three systems. The paddocks were fenced with high tensile fencing and connected to a solar panel charger or electric fencer to contain the experimental cows within the paddock. Except for the woodland that remained unmanaged, management techniques were applied and employed to the silvopasture and open pasture paddocks. Tree species varied by site, but most common were Paper Birch (*Betula papyrifera*), Bur Oak (*Quercus macrocarpa*), Red Oak (*Quercus rubra*), Red Maple (*Acer rubra*), and Quaking Aspen (*Populus tremuloides*) (**Table 3.2**).

Systems were established in Summer and Fall 2013. Thinning was employed in the silvopasture systems in Fall 2013 when the ground was frozen to avoid soil disturbance. Prior to thinning, a tree inventory was conducted to determine initial tree volume and to mark trees to be removed in order to achieve a basal area of 9.2 - 10.3 $m^2\ ha^{-1}$. This basal area was determined to be appropriate for the study and for the study sites. **Table 3.3** presents the project sites' initial and final conditions. A mix of 1.13 kg timothy (*Phleum pratense*) and 2.7 kg red clover (*Trifolium pretense*) were applied to the 0.4 ha open pasture and silvopasture paddocks in late fall 2013 when the ground was frozen. Prior to seeding, a soil test was conducted at all sites to determine soil nutrient status and to adjust fertility of the soil. Based on soil nutrient analysis, the silvopasture and open pasture paddocks were fertilized with urea 46-00-00 and potash 00-00-60 based on the recommendation of the University of Minnesota Soil Analytical Lab. In Winter 2014, the silvopasture and open pasture paddocks were over-seeded with the native grasses including slender wheatgrass (*Agropyron* *trachycaulum*)(2.24 kg ha^{-1}), fringed brome (*Bromus ciliates*)(2.24 kg ha^{-1}), and Virginia wild rye (*Elymus virginicus*)(4.48 kg ha^{-1}), to increase native grass presence in the pasture.

3.3.3. *Grazing Management*

Four cow-calf pairs were assigned to each system paddock each year; pairs differed between years.

Grazing began each spring when forage height averaged 20 cm (25 June 2014; 11 June 2015). Grazing continued until any paddock reached an average forage height of 7-10 cm (an average of 20 days in 2014; 15 days in 2015). A fallow period occurred after each introduction to allow for forage regrowth; cow-calf pairs were re-introduced into paddocks when forage reached an average of 20cm in height (late July to early August). All systems at each site received the same grazing management and timing. The grazing season ended in late August/early September. Cattle had full access to the 2.02-ha paddocks for the two 15-day grazing periods each growing season in 2014 (**Table 3.4**) and 2015 (**Table 3.5**).

3.3.4. Vegetation Sampling

A vegetation sampling technique to measure frequency was employed following the methods outlined in Elzinga et al. (1989). Five permanent vegetation transects were identified in each of the 2.02-ha paddocks. Vegetation transects measured 30 m in length; a half meter square quadrat was placed next to the transect line every 3 meters. Each species within the quadrat boundaries was identified and recorded. This method was repeated for each transect and for each paddock three times each growing season to represent early, mid and late season species. Species assessments were completed before cattle were introduced to allow for maximum success and accuracy regarding identification.

3.3.5. Species Diversity & Richness

Forage plant community diversity was described by species richness and diversity. Species richness represents the total number of species recorded in one transect line. Species diversity was described using the Shannon-Wiener index, which is based on information theory and is well represented in the ecological literature (Lindgren and Sullivan 2012). Both richness and diversity were calculated using the vegan package in R (Oksanen et al. 2016).

3.3.6. *Soil Health*

Soil samples were analyzed at the beginning (Fall 2013) and end of the project (September 2015). Eight soil samples were taken to a depth of 6 inches randomly throughout one third of each paddock to create three composite samples for each 2.02-ha treatment paddock. Samples were analyzed by the University of Minnesota Soil Testing Laboratory for pH, percent organic matter, phosphorus, and potassium.

3.3.7. *Statistical Analysis*

Analyses were performed in R 3.2.4 (R Core Team 2016). Linear models were created for each year separately. Three-way Analysis of Variance (ANOVA) tests were performed to test for all main effects and interactions on the site, season and treatment factors. Post hoc tests were performed using Tukey's HSD to determine pairwise differences. Pearson's product-moment correlation coefficient was used to test for correlation.

3.4. Results

3.4.1. *Species Diversity*

In 2014, species diversity in the woodland systems was greater than in the open pasture and silvopasture systems ($p<0.05$). The mid-season species diversity was marginally higher than the early season ($p=0.06$), but no differences were observed for the late season ($p>0.1$). The magnitude of these differences resulted in significant site X treatment ($p<0.05$) and season X treatment ($p<0.05$) interactions. The interaction between season and site was also significant ($p<0.5$) indicating that the effect of season was different at each site (**Table 3.6**).

In 2015, species diversity in the open pasture system was lower than the silvopasture and woodland systems ($p<0.05$). The late season also showed lower species diversity than the early and mid-season ($p<0.05$). The significant site main effect revealed that the species diversity at Booth's site was significantly higher than at Caughey’s and Moe’s ($p<0.05$). Significant site X treatment and season X treatment interactions ($p<0.05$) reveal differences in magnitude between sites and seasons effect on treatment (**Table 3.6**).

3.4.2. *Species Richness*

In 2014, the species richness in the woodland system was greater than in the open and silvopasture systems ($p<0.05$). Results show significant interactions between treatment and site ($p<0.05$), treatment and season ($p<0.05$), and site and season ($p<0.05$) (**Table 3.6**).

In 2015, the species richness in the open pasture was significantly lower than in the silvopasture and the woodland systems ($p<0.05$) (**Table 3.6**).

3.4.3. *Soil Health*

The post study soil fertility test revealed that the open pasture had a smaller percent organic matter than the silvopasture and woodland systems ($p<0.05$) (**Table 3.7**). There was also a significant site main effect showing that Caughey’s site had a higher percent organic matter than Booth’s and Moe’s sites ($p<0.05$) (**Table 3.7**). Across sites, the pH in the open pasture was significantly higher than in the silvopasture ($p<0.05$) (**Table 3.7**) and marginally higher than the woodland system ($p=0.1$). There were no significant treatment or site effects for potassium and phosphorus content.

Soil pH was negatively correlated with species richness ($p \leq 0.05$, r^2=-0.68) and diversity ($p \leq 0.05$, r^2=-0.67) (**Figure 3.1**).

3.5. Discussion

3.5.1. *Species Diversity and Richness*

Very few studies have compared species diversity and richness directly between silvopasture, open pasture and woodland systems. However, Garrett et al. (2004) claims that forage species under a forest canopy were more diverse than forage species in open pasture systems, while (Orefice 2007) found no significant difference in diversity between silvopasture, thinner forest, and open pasture systems. More research exists on the effect of thinning and fertilization on species diversity and richness, both of which were used in the establishment of the silvopasture systems.

Fertilization has been shown to decrease species richness and diversity due to the principles of competitive exclusion (Proulx and Mazumder 1998; Thomas et al. 1999; Lindgren and Sullivan 2012; Lindgren and Sullivan 2014). The theory of competitive exclusion predicts that as productivity increases, a select few species tend to dominate and outcompete other species resulting in exclusion of less competitive species and ultimately a community with lower diversity and possibly richness. This relationship between richness and diversity and fertilization has been reported by several studies (Proulx and Mazumder

1998; Thomas et al. 1999; Lindgren and Sullivan 2012; Lindgren and Sullivan 2014).

While thinning has been shown to increase species diversity by increasing available resources (Thomas et al. 1999), it has also been shown to decrease species diversity due to increased dominance by one or a few species (Alaback and Herman 1988). This is a likely explanation in this study due to increased presence of seeded species (timothy and red clover). It is however possible that in 10 years this study site will see increased structural diversity as well as species diversity and richness, as is noted by Lindgren et al. (2006). Some species may be more sensitive to disturbance and were therefore eradicated during the thinning process (Lindgren et al. 2006). Wang et al. (2006) found that natural recovery methods resulted in higher species diversity than single seed methods and multi-seed methods, suggesting that seeding can promote dominance of a few species rather than overall diversity.

The system differences for species diversity and richness reveal that woodland systems generally had higher diversity and richness while open pastures had lower. The species diversity and richness of the silvopasture system generally fell between that of the woodland and open pasture systems. It may be acknowledged that forests provide superior buffering as well as wildlife habitat compared to open systems. However, considering that land is a limiting resource in many agricultural settings, keeping forests solely for the environmental value is often not a preferred or viable option. Therefore, silvopasture can be seen as a compromising system which can keep some of the environmental benefits of a forest while allowing grazing access and increasing the value of the land. Through proper management, silvopasture has been shown to increase environmental benefits as well as economic ones through livestock grazing (Garrett et al. 2004). Lindgren and Sullivan (2012) found that as forage opportunities increased (i.e. increased forage production), cattle grazing pressure increased. This increased cattle grazing pressure led to reductions in herb volume. In our study, differences between season could be due to the increased grazing pressure throughout the summer, leading to decreased diversity and richness.

While site differences were only significant in 2015, the site interactions with treatment and season reflect the impacts that location and therefore environmental conditions can have on treatment and season.

The increased diversity and richness in silvopasture and woodland sites compared to open pasture might lead to increased pollinator presence as well as increased vertebrate and invertebrate presence. Increased plant diversity also allows for resilience as we proceed forward and consider the impacts of climate change, as resiliency is seen as protection against unanticipated changes in weather patterns.

This study might not be long enough to detect changes that will occur in the silvopasture compared to the woodland sites due to opening the canopy and increasing light, however the seeding that occurred also may have counteracted this effect.

3.5.2. *Soil Health*

Differences in organic matter content between the sites reflect differences in past management practices as well as environmental conditions. Sites with higher percent organic matter might have had more frequent fertilization as part of their management strategies or they might have been managed with more intensive grazing systems. It is possible that the length of time the trees have been present on the land and/or when they were cleared to form the open pasture could have an impact on the soil health. The presence of tree as well as increased vegetation tends to increase soil health as we see with the silvopasture and woodland sites having higher soil organic matter than the open pasture across sites.

The negative correlation between pH and species diversity and richness suggests that a lower pH benefits a larger variety of plant species and promotes a more diverse ecosystem. While we were unable to measure any more specific microclimatic changes in this study, other studies have found that trees can provide a diverse soil community through root interactions and mycorrhizae (He et al. 2006).

While this study shows that systems with trees can have healthier soils and more diverse plant communities, others have shown that agroforestry systems are more sustainable suggesting that, if managed, these soils will remain healthy due to the consistent interaction between trees, herbaceous vegetation and soil microorganism communities. In the open pasture systems, it might be necessary to fertilize more regularly to supplement the soil due to nutrients escaping the soil and not being added back in, as they are when trees drop their leaves. The contribution of leaf litter to the soil can augment soil nutrients that might have been used up by plants over the season.

3.6. Conclusions and Implications

Silvopasture systems have the potential to provide greater environmental benefits than open pasture systems through increased species diversity and richness as well as improved soil health. Silvopasture, as a combination of open pasture and woodland systems, can be seen as a meeting point between these two systems allowing the productivity of livestock grazing to continue while preserving the advantages woodland systems can have on the environment, specifically in terms of water quality. Increased species diversity and richness can lead to improved cattle health and productivity through diverse diets, while soil organic matter improves forage and tree growth and health.

The differences seen between years and sites reveal that environmental conditions, past management practices, and weather conditions can influence the outcome of these different systems. Before implementation of silvopasture systems research should be completed to determine environmental conditions and past management practices as these might impact the success of the project. Further research is necessary to understand how these outside factors might directly influence projects and the management of the site.

Chapter 3 Tables

Table 3.1. Summary of soil characteristics of each paddock at each site.

Site	Soil Types	Slope	pH	Soil Texture
Booth				
Open Pasture	DeMontreville-Mahtomedi-Cushing complex	0-40%	5.6	Coarse
	Sandwick loamy sand			
Silvopasture	DeMontreville-Mahtomedi- Cushing complex	2-40%	5.1	Coarse
	Cushing loam			
	Alstad fine sandy loam			
Woodland	DeMontreville-Mahtomedi- Cushing complex	3-40%	5.3	Medium
	Warba very fine sandy laom			
Caughey				
Open Pasture	Chetek-Seelyeville ponded complex	0-15%	5.7	Coarse
Silvopasture	Nokay-Prebish complex	0-15%	5.4	Coarse
	Chetek-Seelyeville ponded complex			
Woodland	Chetek-Graycalm complex	0-15%	5.4	Coarse
Moe				
Open Pasture	Bushville loamy sand	0-4%	5.3	Coarse
	Brainerd sandy loam			
Silvopasture	Chetek-Graycalm complex	6-12%	5.3	Coarse
Woodland	Chetek-Graycalm complex	0-6%	5.3	Coarse

Table 3.2. Common tree species found in each silvopasture paddock. Species are expected to be similar in woodland paddocks at the same site***.***

Booth	Caughey	Moe
Betula papyrifera	*Populus tremuloides*	*Pinus banksiana*
Quercus rubra	*Acer Rubrum*	*Betula papyrifera*
Acer rubrum	*Quercus macrocarpa*	*Quercus macrocarpa*
Prunus serotina	*Populus balsamifera*	*Quercus rubra*
Populus tremuloides	*Ulmus americana*	
Ulmus Americana	*Prunus serotina*	
Fraxinus pennsylvanica		

Table 3.3. Summary of treatment establishment and management occurring from summer 2013 to spring 2014.

System	Initial Condition	Management Actions	Final Condition
Woodland	BA= 16-18 $m^2 ha^{-1}$ Average DBH= 30cm	None	BA= 16-18 $m^2 ha^{-1}$
Silvopasture	BA= 16-18 $m^2 ha^{-1}$ Average DBH= 30cm	Thinning Broadcast Seeding Fertilization	BA=9.2-10.3 $m^2 ha^{-1}$
Open pasture	BA=0-0.5 $m^2 ha^{-1}$	Broadcast seeding Fertilization	BA=0-0.5 $m^2 ha^{-1}$

Table 3.4. Cow introduction dates and total pasture and fallow days for 2014.

2014		Introduction 1 Dates				Introduction 2 Dates			
	Cow-Calf Paris	Introduction	Removal	Total Days 1	Total Days Fallow	Introduction	Removal	Total Days 2	Total Pasture Days
Booth									
Open Pasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Silvopasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Woodland	4	25-Jun	14-Jul	19					21
Caughey									
Open Pasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Silvopasture	4	25-Jun	14-Jul	19	9	23-Jul	13-Aug	21	40
Woodland	4	25-Jun	14-Jul	19					21
Moe									
Open Pasture	4	24-Jun	5-Jul	11	39	13-Aug	10-Sep	28	39
Silvopasture	4	24-Jun	5-Jul	11	39	13-Aug	10-Sep	28	39
Woodland	4	24-Jun	5-Jul	11					11

Table 3.5. Cow introduction dates and total pasture and fallow days for 2015.

2015									
		Introduction 1 Dates				Introduction 2 Dates			
	Cow-Calf Paris	Introduction	Removal	Total Days 1	Total Days Fallow	Introduction	Removal	Total Days 2	Total Pasture Days
Booth									
Open Pasture	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Silvopasture	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Woodland	4	13-Jun	2-Jul	19	29	31-Jul	12-Aug	12	31
Caughey									
Open Pasture	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Silvopasture	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Woodland	4	11-Jun	30-Jun	19	28	28-Jul	12-Aug	15	34
Moe									
Open Pasture	4	8-Jun	20-Jun	12	60	19-Aug	2-Sep	14	26
Silvopasture	8	8-Jun	20-Jun	12	60	19-Aug	2-Sep	14	26
Woodland	0								

Table 3.6. Average species diversity and richness for 2014 and 2015 in open pasture, silvopasture and woodland systems across the three sites: Booth, Caughey and Moe. Average across sites and across treatment are also reported. Different letters indicate significant differences (p<0.05).

	2014				2015			
	Booth	Caughey	Moe	**Average**	Booth	Caughey	Moe	**Average**
Species Diversity								
Open Pasture	2.1	1.8	2.0	**2.0 b**	2.7	2.1	2.7	**2.5 a**
Silvopasture	1.9	2.0	1.9	**1.9 b**	2.9	2.7	2.5	**2.7 b**
Woodland	2.0	2.3	2.0	**2.1 a**	2.8	2.9	2.7	**2.8 b**
Average	**2.0**	**2.0**	**1.9**		**2.8 a**	**2.6 b**	**2.6 b**	
Species Richness								
Open Pasture	11.3	8.1	10.1	**9.9 b**	19.5	11.1	18.9	**16.5 a**
Silvopasture	9.8	9.6	8.8	**9.4 b**	24.7	21.5	17.1	**21.1 b**
Woodland	11.0	13.3	10.1	**11.5 a**	22.1	23.9	19.2	**21.7 b**
Average	**10.7**	**10.4**	**9.7**		**22.1 a**	**18.8 b**	**18.3 b**	

Table 3.7. Average percent soil organic matter and pH in open pasture, silvopasture and woodland systems across the three sites: Booth, Caughey and Moe. Average across sites and across treatment are also reported. Different letters indicate significant difference (p<0.05).

	2015			
	Booth	Caughey	Moe	**Average**
pH				
Open Pasture	5.57	5.67	5.30	**5.51 a**
Silvopasture	5.13	5.37	5.33	**5.28 b**
Woodland	5.27	5.43	5.30	**5.33 ab**
Average	**5.32**	**5.49**	**5.31**	
Percent Organic Matter				
Open Pasture	2.70	4.63	2.53	**3.29 a**
Silvopasture	3.43	5.73	2.77	**3.98 b**
Woodland	3.67	5.00	3.43	**4.03 b**
Average	**3.27 b**	**5.12 a**	**2.91 b**	

Chapter 3 Figures

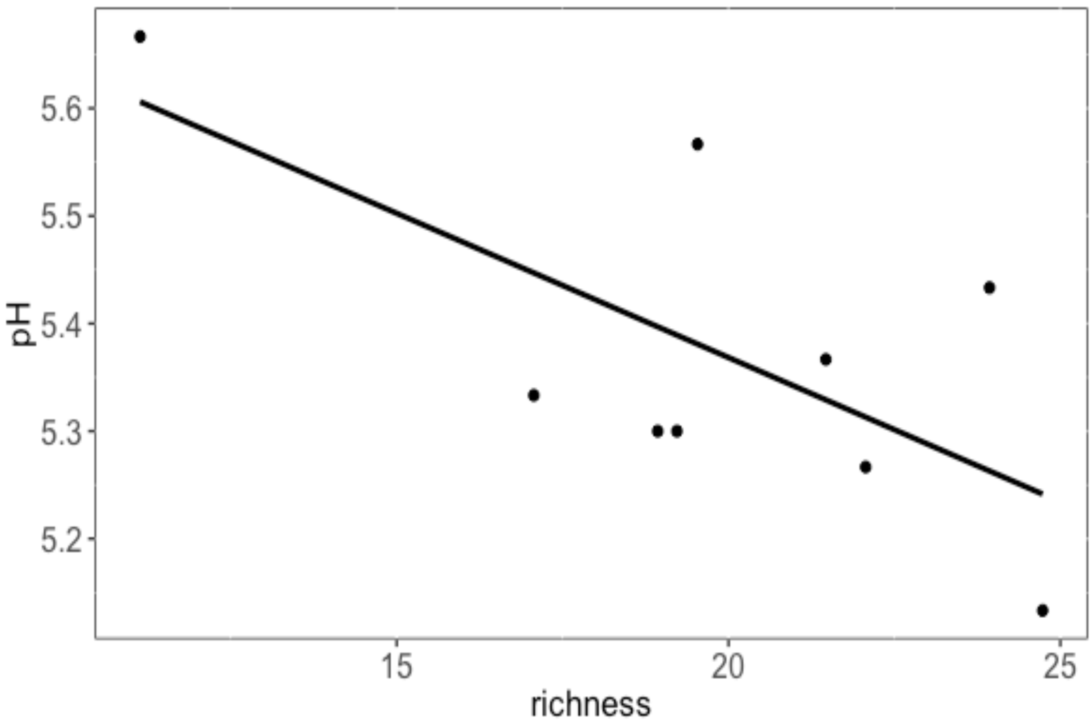


Figure 3.1. pH and species richness linear regression line for all sites and treatments in 2015 ($p \leq 0.05$, $r^2 = -0.68$).

Chapter 4. Silvopasture in Central Minnesota: perceptions of landowners and natural resource professionals

4.1. Synopsis

Before a new land management technique can be developed and encouraged in an area it is important to understand perceptions of landowners and natural resource professionals regarding the management technique. Silvopasture is a new agroforestry technique for central Minnesota that shows potential for improving woodland grazing management techniques throughout the region. Silvopasture intentionally and intensively combines forage, trees and livestock in an integrated system. This study administered surveys to landowners and natural resource professionals in central Minnesota to determine perceptions, including barriers to adoption, of silvopasture prior to further implementation and educational programs. Survey results show that while silvopasture is a new concept and many individuals are unfamiliar with it, there is interest in learning more. However, individuals generally have economic concerns regarding the implementation of silvopasture and feel that more technical training, especially in terms of tree management, is needed. With more research, education and technical support silvopasture might become a reputable management technique in central Minnesota.

4.2. Introduction

Minnesota has the second highest area of forested land in the Midwest, USA after Michigan, with a total 6.8 million hectares (Garrett et al. 2004). Twelve percent of this forestland is located on farms. Approximately 177,719 hectares of woodlands on farms are grazed (NASS 2012). Passive woodland grazing is practiced on farm woodlands to take advantage of available forage after a canopy opening disturbance. However, it is often not managed to its fullest potential (Sharrow 1998; Garrett et al. 2004). Livestock production is a predominant sector of agriculture in Minnesota, making up 47% share by value of the agriculture sector, hence, it is important to optimize grazing operations (Minnesota Deperatment of Agriculture 2015). This presents an opportunity for silvopasture application, to improve on current woodland grazing systems. As an agroforestry practice that intentionally integrates trees, forage, and livestock as one intensively managed system, silvopasture aims to increase the economic value of the land through diversification of income and increasing the environmental value of the land.

While silvopasture is a common practice in the southeast United States, it is a new concept in Minnesota with limited information and research available on hardwood silvopasture especially in the upper Midwest. Previous studies have shown that there are a variety of potential barriers and constraints to silvopasture adoption in the region, and the benefits of silvopasture may or may not be known to landowners. Landowners' perception of a technology plays a key role in agricultural technology adoption, in addition to market and environmental factors (Frey et al. 2012). Adoption is also influenced by individual’s own experiences as well as the experiences of others, such as friends and neighbors. (Frey et al. 2012). Understanding the social and environmental aspects of silvopasture adoption is important because these factors are often not included in financial analyses of silvopasture systems (Shrestha et al. 2004).

Previous studies regarding silvopasture adoption and perceptions in the Americas have found that the main reasons for silvopasture adoption are land stewardship, income diversification, environmental benefits and government support (Shrestha et al. 2004). Uncertainties regarding regulations and the long-term nature of silvopasture investments are major challenges for its adoption (Shrestha et al. 2004). Other primary barriers of adoption include the high cost of establishment and the lack of information and knowledge about the practice and management techniques (Workman et al. 2004; Calle 2008). Other barriers identified by natural resource professionals include an incompatibility between multiple outputs, negative impacts of livestock on trees, and soil productivity problems(Zinkhan and Mercer 1996; Workman et al. 2004). Calle (2008) also observed a change in farmers’ attitudes over time, coming to accept that trees and pasture can exist together as well as understanding the ecological processes involved in sustainable practices.

As a new practice being promoted in Minnesota and the upper Midwest, it is important to understand local landowner and natural resource professionals’ perceptions of silvopasture as well as barriers to adoption before attempting to encourage silvopasture across the landscape. Through electronic and paper surveys, we attempted to gain an understanding of landowners and natural resource professionals’ perceptions of silvopasture and woodland grazing in central Minnesota. The survey aimed to understand general perceptions of silvopasture including barriers to adoption, as well as differences in opinions between landowners and natural resource professionals.

4.3. Methods

Two separate surveys were developed for natural resource professionals and landowners and approved by the IRB (Institutional Review Board) of the University of Minnesota. Survey questions were developed and pre-tested following methods outlined by Dillman et al. (2009). Individuals were from the following 20 central Minnesota counties: Beltrami, Benton, Carver, Cass, Crow Wing, Itasca, Kandiyohi, Koochiching, Lake of the Woods, McLeod, Meeker, Morrison, Renville, Scott, Sherburne, Sibley, Stearns, Todd, Wadena, and Wright (**Figure 4.1**).

4.3.1. Natural Resource Professionals

The natural resource professionals survey was sent to 431 natural resource professionals throughout Minnesota. The list was taken from the Natural Resource Conservation Service (NRCS), Soil and Water Conservation Districts

(SWCD), and the Farm Service Agency (FSA), and approved MN Stewardship Plan Preparers. The survey was administered in December 2014, via email using Qualtrics online survey manager platform of the University of Minnesota. Forty-one surveys were returned resulting in a response rate of 9.6%.

4.3.2. Landowners

Tailored for landowners that currently have livestock and woodlands in central Minnesota, the survey was developed with inputs from University of Minnesota extensions evaluation specialist. Nongovernmental organizations, such as the Minnesota Cattleman's Association, the Minnesota Milk Producers Association, and the Crow Wing River Basin Forage Council, were consulted and provided inputs to the survey, as these groups have knowledge of our target audience. The survey was developed around demographics, satisfaction with current grazing practices, current use(s) of their woodlands, use of woodlands for grazing, prior knowledge and perceptions of silvopasture, and how they prefer to learn. The database of the Crow Wing River Basin Forage Council and the University of Minnesota Beef Team was utilized to obtain addresses of landowners and livestock producers in 20 central Minnesota counties. Pilot surveys were administered in February 2015 and changes were made accordingly. The final survey was sent to 1,343 landowners by mail in March 2015, representing 10% of the population of landowners and producers in the Crow Wing Forage Council and University of Minnesota Beef team data base.

Postcard reminders were sent by mail to those who had yet responded in April 2015. Surveys were returned at a 15% response rate (201 surveys were returned completed).

4.3.3. Statistical Analysis

Survey results were analyzed with the R statistical software (R Core Team 2016) using descriptive and regression techniques.

4.4. Results

4.4.1. Landowner Survey

Of the respondents for the landowner survey 95% were male, 4% were female and 1% were unreported. Only 3% of respondents were younger than 34, with the largest percent reporting 55-69 years of age at 41% (**Table 4.1**). Household annual income was quite spread out however the largest percent was 31% of respondents earning between 25 and 49 thousand US dollars per year. Nearly all (99.5%) respondents described themselves as white. Farmer and livestock producer were the most common occupation with farmer only at 30%, livestock producer only at 29% and farmer and livestock producer at 14% (**Table 4.2**).

The number of landowner respondents practicing management-intensive grazing was split almost evenly between those practicing management intensive grazing (45%) and those not practicing it (51%). Sixty-two percent of respondents practice unmanaged woodland grazing; compared to 30% that practice silvopasture.

Landowner respondents indicated increased shade for livestock (mean=4.22: scale of 1 to 5, where 1 is the lowest) and reduced soil erosion and improved soil quality (mean=3.95) as the most important benefits of silvopasture. Landowner respondents did not believe more rapid weight gain (mean=3.27) nor increased calving survival rates (mean=3.31) to be strong benefits of silvopasture (**Figure 4.2**). Landowners responding ranked lack of information/knowledge (mean=3.72) and expense of additional management (mean=3.6) as major obstacles to the use of silvopasture. Lack of technical assistance and lack of equipment (mean 3.5 and 3.45) ranked next highest in importance (**Figure 4.2**).

Landowner respondents were unlikely to start practicing silvopasture (0.58%), while 40% said they would consider it and 30% said they would not practice silvopasture (**Table 4.3**). Landowners are most interested in learning about pasture management (mean 3.63 on a scale of 1 to 4, 1 being not interested, 2 being a little interested, 3 being somewhat interested and 4 very interested) followed by livestock management (mean 3.85), silvopasture establishment and management (mean 3.63) and lastly tree management (mean 3.62) (**Table 4.5**). Landowners responded that cutting trees in existing grazed woodlands to allow light for forage growth (36%) and managing trees on the edge of existing pastures (29%) were the most feasible methods for implementing silvopasture on their land. Only 6% of landowners indicated that integrating livestock into existing tree farming systems was a feasible method to establish silvopasture on their land (**Table 4.7**).

Landowner respondents reported neighbors, trade journals and extension educators (34%, 33% and 32%, respectively) as the top three sources for forage information. The top three rankings for information regarding agriculture were the same as for information regarding forage, with slightly higher percentages due to a larger number of respondents answering about agriculture than forage (52%, 50% and 48% respectively). Overall, neighbors were the most frequently mentioned source for information regarding agriculture, forage or forestry, followed by trade journals and then extension educators (57%, 55%, 51%, respectively).

4.4.2. Natural Resource Professionals Survey

Of those who responded to the natural resource professionals (NRPs) survey, 39% were female and 61% were male, and ages ranged from 18 to 69 years with 27% between 18 and 34; 41% between 33 and 54; and 32% between 44 and 69 (**Table 4.1**). The majority (93%) of respondents identified their ethnicity as white. Of those who responded 54% of the individuals work for SWCD (Soil and Water Conservation Districts) and 32% worked for the NRCS (Natural Resource Conservation Service). The remaining 14% is split evenly between those who work for the FSA (Farm Service Agency) and those who are private consultants (**Table 4.4**). More than two thirds of the individuals have been working as a natural resource professional for 6-15 years and 30% of individuals have been working for 21-30 years (**Table 4.4**).

The highest number of respondents (37%) reported that crop production is the most common agricultural practice that they help landowners manage followed by pasture with no trees (34%) and pasture with trees (32%) (**Figure 4.3**). Twenty seven percent of NRPs reported that they use silvopasture as a management tool, mostly between 1 and 25 acres (22%) while 73% of respondents did not respond indicating lack of use of silvopasture (

Figure 4.4).

Natural resource professional (NRP) respondents indicated increased shade for livestock (mean=4.06: scale of 1 to 5, where 1 is the lowest) and diversified production (mean=3.94) as the most important benefits of silvopasture. Shade for livestock was identified as the most agreed benefits of silvopasture among natural resource professionals, similar to that of the landowner respondents. The next two most agreed with benefits for NRPs were increased diversity of plants/insects and wildlife habitat (both with mean=3.88) (**Figure 4.5**). NRP respondents indicated lack of information/knowledge as the most substantial obstacle to silvopasture adoption (mean=3.91), which was also the most substantial obstacle for landowner respondents. The next most substantial obstacle was identified as expense of additional management followed by lack of financial incentive (means=3.64. 3.63) (**Figure 4.5**).

Most natural resource professional respondents know at least a little about silvopasture, with only 15% reporting they know nothing about the practice. However, only 2% of the respondents indicated strong knowledge about silvopasture. NRP respondents are likely to consider recommending silvopasture adoption (53%), but are not as keen on starting to recommend it (7.5%). Thirty-two percent responded that they will continue to recommend silvopasture, while only 7.5% said they will not recommend it (**Table 4.3**). On average NRP respondents were interested in learning more about different aspects of silvopasture. NRPs were generally less interested in learning more about silvopasture than landowners, (means of 2.55 and 3.75 respectively). NRPs, however, are most interested in learning about tree management (mean 2.7) compared to the other categories (**Table 4.5**).

NRP respondents reported trade journals and neighbors/other farmers (mentioned by 43 and 34 percent NRPs, respectively) as the top sources for forage information. The top rankings for information regarding forestry were professional consultants and trade journals (both 32%). The top rankings for agriculture were trade journals (59%), extension educators (56%), neighbors/other farmers (56%), and professional consultants (56%). Overall extensions educators (70%) were the most frequently used sources of information regarding any of the three subjects (agriculture, forage and forestry) followed by neighbors/other farmers (58%), professional consultants (63%) and trade journals/magazines (63%).

4.5. Discussion

It was surprising how many landowners (30%) and NRPs (40%) said they currently practice or encourage silvopasture in Minnesota, contrary to what Workman et al. (2004) reported, that 26% and 16% of landowners practiced silvopasture in Georgia and Alabama, respectively Of the 30% (61 individuals) of landowner respondents who indicated practicing silvopasture, only 9.8% indicated knowledge about silvopasture, while 16% said they know nothing about silvopasture, 24.5% said they know a little, 23% said they know some, which reveals that there might have been some misunderstanding as to the question or the definition of silvopasture (despite that a definition of silvopasture was given in the survey). Silvopasture was defined in the survey as "*the sustainable management of trees, livestock, and forage on the same area of land. In other words, it is form of <u>intensive management grazing</u> where trees, livestock and forage are INTENTIONALLY MANAGED AND INTEGRATED. Livestock could be cattle, goats, or sheep".* Therefore, it seems that there is room for growth in knowledge even from individuals who already practice silvopasture. Many landowners indicated that they started practicing silvopasture because the land they have is forested, they needed more pastureland, they want to take advantage of existing forage, and they want to manage their woodlands.

Generally, landowners agreed with the benefits of silvopasture listed in the survey, except for the perceived rapid increase in cattle weight gain compared to other forms of grazing they might currently be practicing. However, it was not specified with what these benefits should be compared, and landowners could be comparing to open pasture systems, or woodland grazing or even a combination of the two where animals can move freely between open and wooded areas. Additionally, landowners were more skeptical of increased calving survival rates, overall livestock health and increased forage production/quality. Benefits with which they readily agreed were more related to environmental benefits such as water quality, soil quality/decreased erosion, and wildlife habitat, as well as increased shade for livestock. These findings were consistent with those of Workman et al. (2004) who found that aesthetics, shade, wildlife habitat and soil conservation were the benefits of highest importance to landowners in Alabama and Georgia.

Perceptions of natural resource professionals (NRPs) on silvopasture are consistent with landowners' perceptions. Landowners agreed significantly ($p<0.05$) more than NRPs that soil health and short term returns were benefits of silvopasture (**Figure 4.6**). Overall, a larger percentage of NRPs agreed with some benefits such as diversified production, increased plant/insect diversity, increased wildlife habitat and long-term returns, than landowners (**Figure 4.6**). This could be because of a greater initial knowledge of silvopasture than landowners (**Table 4.6**).

The adoption of silvopasture faces many challenges. Landowner respondents disagreed with the traditional notion that trees and pasture do not mix together, too few trees on property, property too small, and someone recommended against it. It is noteworthy that landowners tend to disagree with these fundamental obstacles that could deter them from adopting silvopastoral practices. If landowners thought that trees and pasture do not mix, then promoting silvopasture would be challenging. The factors that landowners most agreed with in adopting silvopasture include 1) lack of knowledge, 2) lack of technical assistance, 3) expense of additional management, 4) lack of financial assistance, and 5) the lack of silvopasture demonstration sites in Minnesota. Workman et al. (2004) found that main obstacles identified by landowners were lack of equipment, competition of growth resources among system components, lack of land, expense of management and the lack of demonstrations. Lack of land, however was ranked 7th by landowners in this study.

The factors identified by landowners on adopting silvopasture also hold true for NRPs, with major differences being that more NRP respondents agreed significantly more with the following obstacles than landowners: that trees and pasture do not mix ($p<0.05$), someone recommended against it, too few trees on property and lack of demonstrated local successes. This is likely due to the common view in forestry that cattle should be kept out of forests, however with proper management this notion can be combated (Garrett et al. 2004). Also, with a lack of successful demonstration sites in the area there is little evidence to show NRPs that trees and pasture can mix.

Both landowners and NRPs responded that they do not know a lot about silvopasture and generally are interested in learning more about at least some portion of the process. Silvopasture is also not a common practice with 70% of both landowners and NRPs responding that they do not practice silvopasture currently. Additionally, cropland and pasture with no trees were the top two land uses that NRPs are helping landowners manage.

Understanding where landowners acquire information regarding agriculture, forage, and forestry will aid in designing further educational materials. For landowners, neighbors and other farmers are important sources of information, therefore increasing demonstrations sites nearby could help landowners feel more confident about adopting silvopasture. Trade journals and extension educators were also important sources of information and therefore increasing information about silvopasture in trade journals will be important as well as educating extension educators on silvopasture management practices.

Natural Resource Professionals were most interested in learning about tree management along with pasture and livestock management. This increased interest in tree management shows that this is likely the area of silvopasture that NRPs (and landowners) know least about and it might be difficult for NRPs to feel confident managing for tree production and health when they are unfamiliar with tree management, because most of their career has been focused on open pasture management. Including specific information regarding tree management in silvopasture systems as well as contacts for local foresters with silvopasture management experience in educational materials will be essential for NRPs to confidently encourage adoption.

Addressing landowners' economic bottom line is of great concern; thus understanding economic feasibility of silvopasture, and the potential for financial incentives for landowners practicing silvopasture are necessary as these were identified as main concerns of landowners and NRPs about the practice. Time and money are often the biggest constraints a landowner has when trying to adopt a new management technique, and they are not going to be able to overcome these constraints unless the practice can be proven to be economically viable (often with a short term return). Additionally, more specific information will need to be developed to best guide NRPs and landowners regarding ideal forage species in Minnesota for shaded environments, as well as ideal tree species to be combined with cattle and how to care for these trees when cattle are present.

It is likely that landowners will not convert their whole livestock operation to silvopasture and therefore considering how to combine open pasture and silvopasture systems in a way that livestock do not over-occupy one area and to ensure that the benefits to livestock are spread across the season is necessary. Silvopasture management requires the use of a rotational grazing system. As roughly half of landowner respondents are not currently practicing management intensive grazing, moving from continuous grazing to rotational grazing can require added time and monetary investments to the already challenging establishment of silvopasture systems. Encouraging landowners to switch to a rotational grazing system before adopting silvopasture systems might help to alleviate this additional investment.

4.6. Conclusions

The survey results helped us to understand some current management practices as well as perceptions regarding silvopasture including perceived benefits and obstacles to adoption. While most landowners and natural resource professionals do not know much about silvopasture, they are interested in learning more about the practice, and the concept of rotational grazing to better manage their lands for environmental and economic benefits. As expected, many factors were identified as causes for the low adoption of silvopasture by landowners and its promotion by natural resource professionals, such as time and monetary requirements to establish the practice, lack of demonstration sites, and the lack of technical assistance. NRPs are more skeptical of silvopasture adoption than landowners. They are more apt to believe that trees and pasture do not mix and that too few trees on the landscape will be a significant obstacle. With this planting trees into existing pasture was not seen as feasible a technique as turning a current woodlot into a silvopasture system and using existing trees on the edge of pastureland.

Results of the survey have been used to develop educational programming about silvopasture in Minnesota including the development of a best management practice to serve as an educational material in silvopasture adoption and promotion.

Chapter 4 Tables

Table 4.1. Percent of landowner and NRP (natural resource professional) respondents in each gender, age, and ethnicity category.

	Landowners		NRP	
	Frequency	**%**	**Frequency**	**%**
Gender				
Male	190	95.48	25	60.98
Female	9	4.52	16	39.02
Total	199	100	41	100
Age				
18-34	6	2.99	11	26.83
35-54	41	20.4	17	41.46
55-69	83	41.29	13	31.71
70 & over	71	35.32	0	0
Total	201	100	41	100
Ethnicity				
White	201	99.5	38	100
American Indian	1	0.5	0	0
Asian/Pacific Islander	0	0	1	2.63
European	0	0	1	2.63
Total	202	100	38	100

Table 4.2. Frequency and percent of landowner respondents in each occupation and income category.

	Frequency	%
Primary Occupation		
Farmer	87	34.8
Livestock Producer	86	34.4
Business Owner	12	4.8
Other	65	26
Total	250	100
Household Income		
<$25,000	16	8.56
$25,000-$49,000	63	33.69
$50,000-$74,000	47	25.13
$75,000-$99,000	27	14.44
$100,000-$149,000	20	10.7
$150,000+	14	7.49
Total	187	100

Table 4.3. Likelihood of landowners and NRPs to adopt or recommend adoption of silvopasture.

	Landowners		NRP	
	Frequency	**%**	**Frequency**	**%**
Will not	53	30.81	3	7.5
Will consider	68	39.53	21	52.5
Will start	1	0.58	3	7.5
Will continue	50	29.07	13	32.5
Total	172	100	40	100

Table 4.4. Frequency and percent of Natural Resource Professional (NRP) respondents for each employer category and number of years in field category.

	Frequency	%
Employer		
SWCD	22	53.66
NRCS	13	31.71
Private Consultant	3	7.32
FSA	3	7.32
Total	41	100
Years in field		
1-5	3	7.32
6-10	8	19.51
11-15	8	19.51
16-20	4	9.76
20-25	7	17.07
26-30	5	12.2
Over 30	6	14.63
Total	41	100

Table 4.5. Landowner and Natural Resource Professional (NRP) interest in learning more about silvopasture components on a scale of 1-4 (not interested, a little interested, somewhat interested, very interested).

	Landowner		**NRP**	
	Mean	SD	Mean	SD
Silvopasture establishment and management	3.63	1.03	2.48	0.94
Pasture management	3.9	0.98	2.5	1.02
Tree management	3.62	0.98	2.7	1.02
Livestock management	3.85	1.04	2.52	1.06

Table 4.6. Mean landowner and NRP knowledge about silvopasture based on scale from 1-4 where 4= a lot, 3=some, 2=a little, 1=nothing

	Mean	**SD**
Landowners	1.7	0.9
NRP	2.29	0.74

Table 4.7. Most feasible methods for establishing silvopasture on their land or lands they manage.

	Landowners		NRP	
	Frequency	**%**	**Frequency**	**%**
Cutting trees in existing graze-wooded land to allow light for forage growth	73	26.26	14	22.22
Planting trees into existing marginal pastureland	35	12.59	13	20.63
Managing trees on the edge of existing pastures	59	21.22	16	25.4
Integrating livestock into existing tree farming systems (e.g., red pine plantations)	13	4.68	5	7.94
I do not feel silvopasture is appropriate or feasible on the farm(s) I manage for others	30	10.79	1	1.59
I do not know	68	24.46	14	22.22
Total	278	100	63	100

Chapter 4 Figures

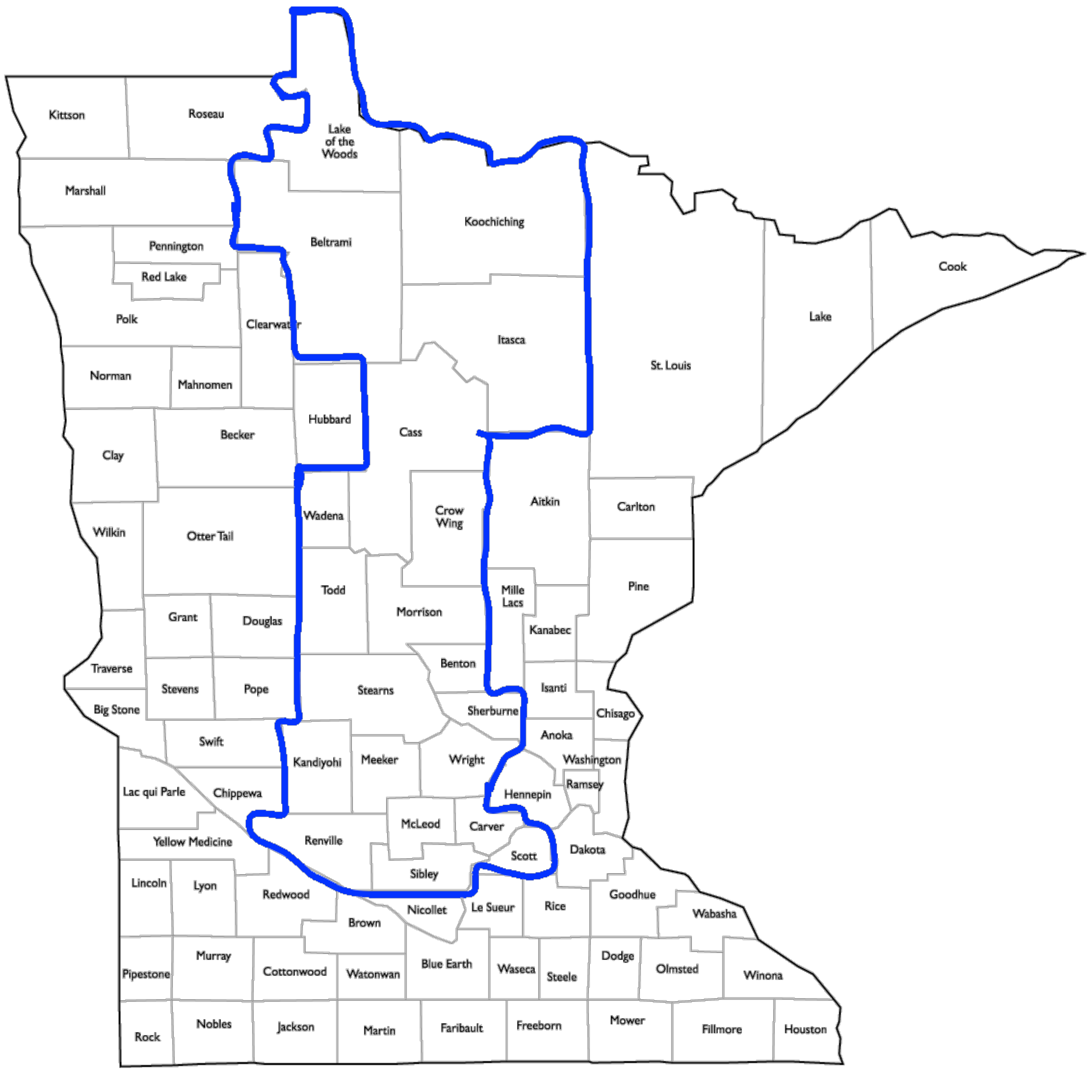
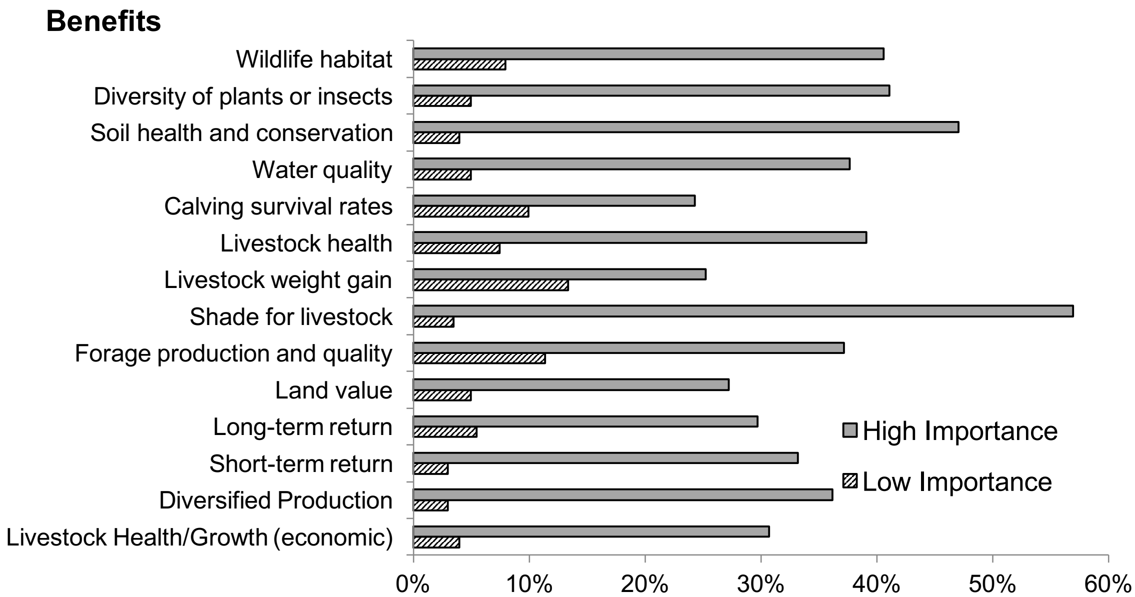


Figure 4.1. Survey respondents resided in the counties outlined in blue in Central and North Central Minnesota.



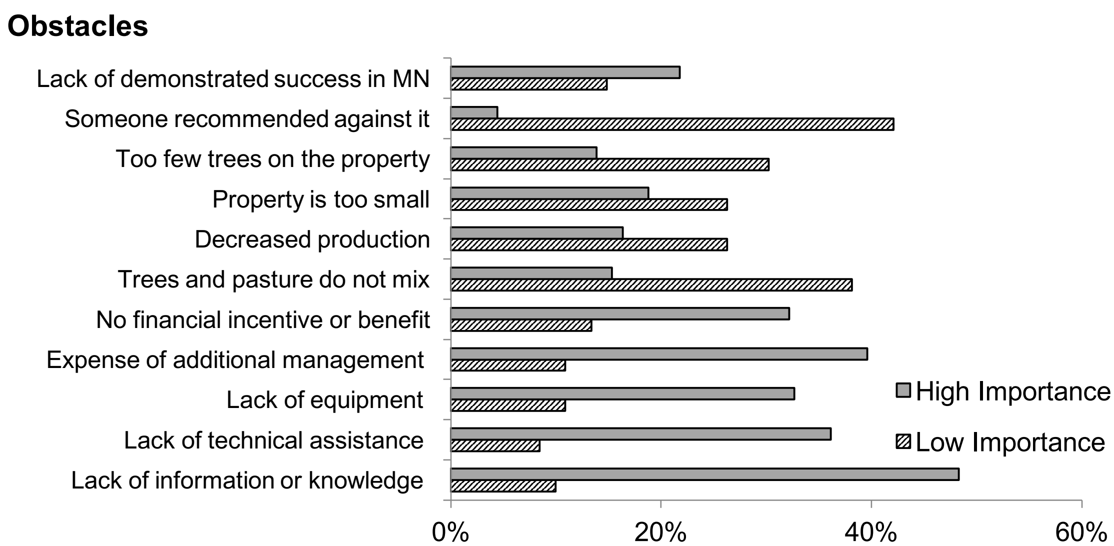


Figure 4.2. Benefits and obstacles of silvopasture as ranked by landowners. High importance corresponds to rank of 4 or 5 out of 5. Low importance corresponds to rank of 1 or 2 out of 5.

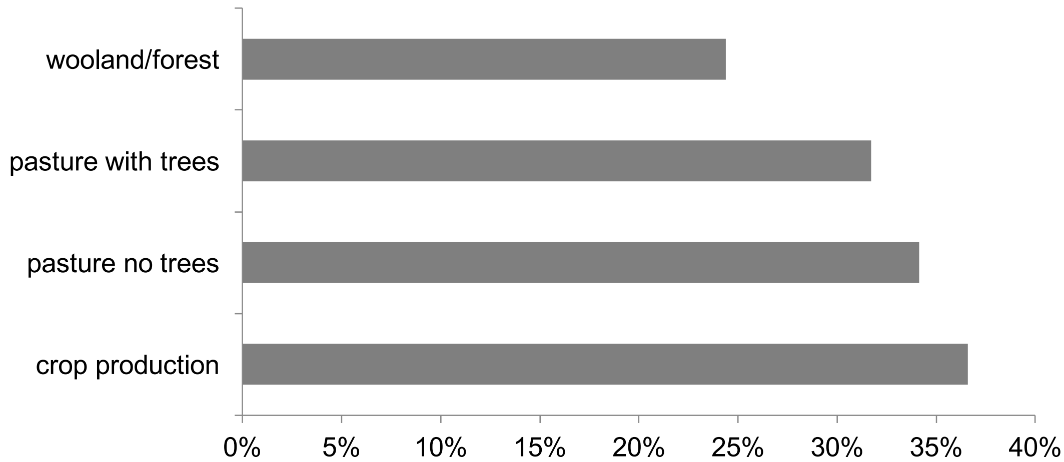


Figure 4.3. Percent of NRPs managing land in each agricultural practice.

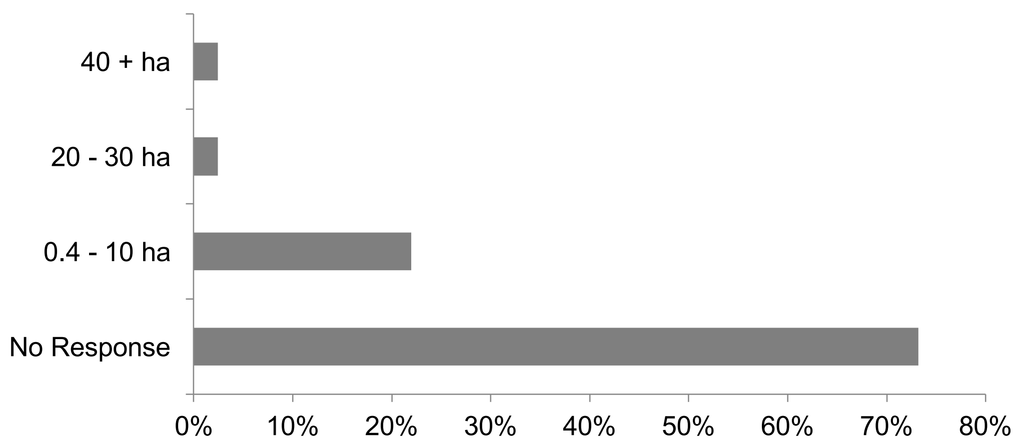
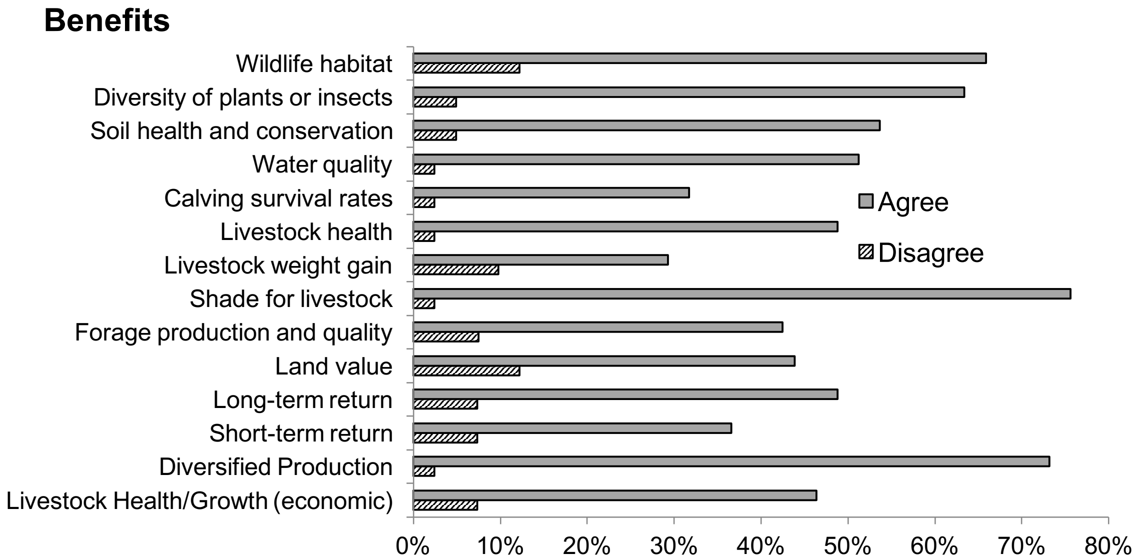


Figure 4.4. Percent of NRPs managing silvopasture in each hectare category.



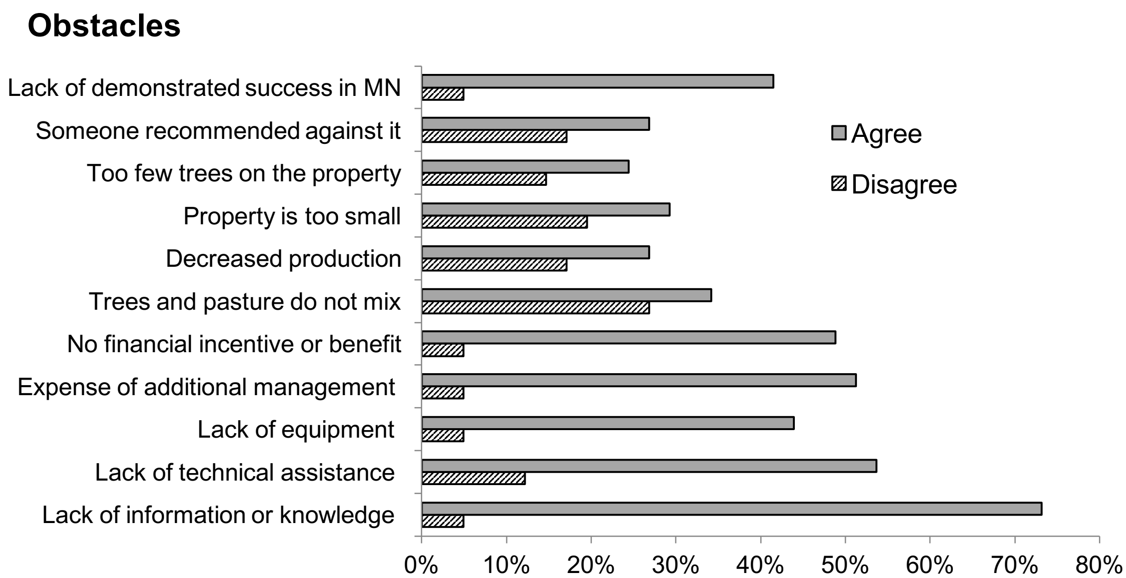


Figure 4.5. Benefits and obstacles of silvopasture as ranked by NRP.

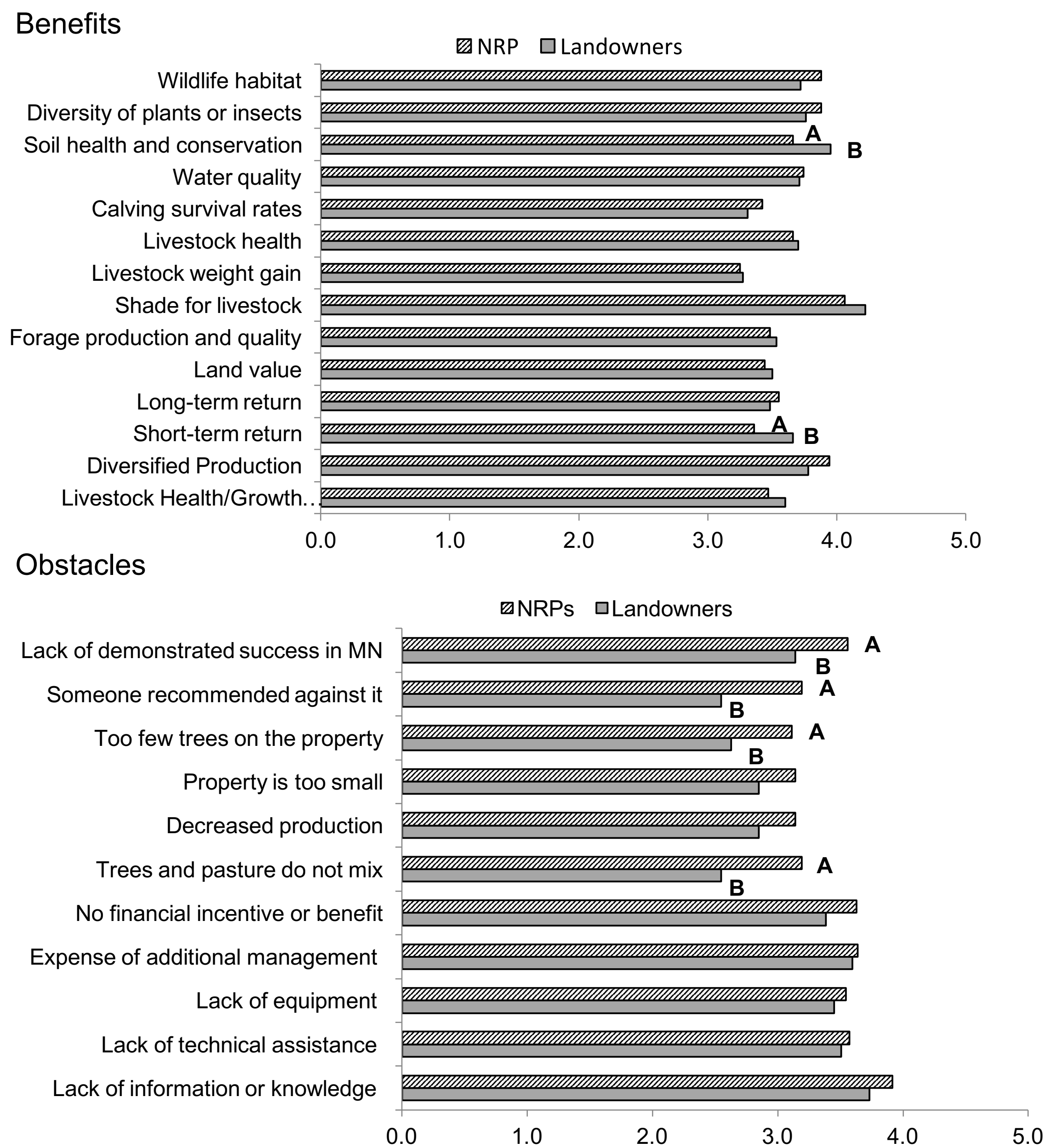


Figure 4.6. NRP and landowner responses regarding benefits and obstacles of silvopasture. Mean response on a scale of 1-5, 5 being strongly agree, 1 being strongly disagree. Different letters within each benefit or obstacle indicate significant difference ($p < 0.05$) between NRP and landowner views.

Chapter 5. Conclusions

This research suggests that silvopasture has potential as a viable alternative to unmanaged woodland grazing in central Minnesota. In chapter 1, I outlined the history of woodland grazing and its relevance to central Minnesota as well as identified management requirements and challenges. The microclimate that is present in silvopasture systems can have many desirable effects on forage health and production as well as environmental health and system resiliency as we saw in chapters 2 and 3.

Forage production analysis in Chapter 2 revealed that silvopasture systems had higher forage production than woodland systems, and often comparable forage production to open pasture systems. Forage quality was generally lowest in the open pasture systems, and highest in the woodland systems with the silvopasture systems having medium quality. Therefore, silvopasture systems can obtain higher yields than woodland systems, while maintaining some of the forage quality benefits associated with shade. Seasonal differences also showed that silvopasture and open pasture systems can be used in combination to take advantage of each system at their prime. Silvopasture systems are likely to outperform open pasture during hot and dry months, while open pasture systems can outperform silvopasture in early spring. Lack of livestock weight gain differences between systems reveals that cows perform adequately well in each system, emphasizing that a silvopasture system is an equally suitable environment as an open pasture system.

The livestock component was the most challenging part of this study, as moving and weighing them required a large amount of time and effort from landowner cooperators as well as students. Additionally, due to the limited amount of time in the season, access to a limited number of cows, and inability to move cows frequently, we forfeited the original randomized block design, resulting in reduced power for statistical tests. If we had been able to manage each system at each site individually for optimal forage growth we might have seen more contrasting results, however cattle had to be removed from all systems at the same time for weighing, and therefore systems were not managed based on forage growth, but timing.

In chapter 3 we summarized the environmental effects of silvopasture systems, with the aim of quantifying the positive effects of trees on the landscape. The woodland and silvopasture systems had higher herbaceous species diversity than the open pastures, although woodland systems were often higher than silvopasture systems as well. However, the short duration of the study likely limited our assessment of diversity as changes implemented in the silvopasture are likely still being realized in the understory vegetation. This improved plant species diversity compared to open pasture systems can translate to increased system resiliency as well as potentially increased fauna diversity including important pollinator species. Both silvopasture and woodland systems had higher percent soil organic matter than open pasture systems. This increased soil health, likely in part due to the presence of trees, can lead to increased system resiliency as well as potentially more productive systems that require fewer inputs over time. Hydrological data is still in the process of being compiled and will included in the thesis of Sophia Vaughan.

The survey analysis from chapter 4 suggests that landowners and natural resource professionals are skeptical but interested in silvopasture. It also seems that some landowners have already transitioned to a management practice similar to silvopasture, but perhaps slightly less intensive, as they saw the benefits of opening the canopy and planting forages. We were able to identify some obstacles to adoption that can be addressed such as lack of technical assistance and knowledge, as well lack of financial support and the additional time needed for management. With stronger extension programs in silvopasture and agroforestry in general, these obstacles can be overcome. Specifically, a best management practices (BMP) manual for silvopasture is in the process of being created and made available to local landowners.

Future research efforts should continue to look at optimal grazing management plans and stocking densities for silvopasture systems in Minnesota, as well as specific tree and forage species that perform best together. Additionally, future studies monitoring livestock growth and stress levels could provide an insight into further economic and livestock benefits of silvopasture systems compared to other systems. As silvopasture is adopted by more landowners throughout the region, further surveys should be collected to determine primary reasons for adoption and changed perceptions of silvopasture after adoption.

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